CARBURATION

R. W. A. Brewer

CARBURATION IN THEORY AND PRACTICE

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Including a Criticism of Carburettor Development

A MANUAL OF REFERENCE FOR AUTOMOBILE ENGINEERS AND OWNERS

BY

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PREFACE

THE subject of carburation is one which is vital to the automobile movement and has, therefore, received more scientific attention during the past few years. This has been necessary on account of the demands of the public for wide ranges of engine speed, controllability, and quietness.

The author has been unable to discover much scientific book work dealing with this subject, with the exception of that very useful book of Sorel's upon the subject of alcohol motors. There is, undoubtedly, a considerable interest taken, both by automobile engineers and owners, in the carburettor question, and this has been much greater recently on account of the increased price of fuel.

It is the intention of the author that this book should provide in convenient form information upon the properties of various fuels, how the said fuels require treatment for use in a motor car engine, and

what has been done in the past in order to obtain the necessary data upon which to base the theory.

The user will find much information which will give him a clearer understanding of the principles of carburation and enable him to effect economies in working, and the designer should be saved many hours of labour by the use of the data contained herein.

The closing chapters consist of descriptions of some of the best known carburettors, with criticisms thereon, but the number of carburettors which has been produced is so large that it is impossible to include all.

A certain amount of the information contained herein has been embodied in lectures and papers and press contributions, and is reproduced in a slightly different form by kind permission of the editor of the *Automobile Engineer*, now *Internal Combustion Engineering*, and the editor of the *Automobile* of America.

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CARBURATION

PART I

CHAPTER I

GENERAL OUTLINE

BY the use of the word "carburation," it must be understood that this word will designate the art of mechanically mixing or blending a liquid fuel with a certain amount of air, and that whether this art is carried out to the limits of perfection or not, is an indication of whether the carburation is good or bad. Carburation will be considered to be more or less complete by reason of the manner in which the air is mixed with the molecules of the liquid fuel, or whether the fuel is divided into its finest possible particles in such a way that every particle of fuel is surrounded by a certain quantity of air to the limit of homogeneity of the mixture.

Homogeneity signifies "having the same properties or character in every direction." A homogeneous fuel is one of uniform composition throughout, so that samples taken, however large or small, from any part of the bulk of the fuel are exactly alike in composition. As far as the explosive mixture supplied to an engine is concerned, if two gases are the active agents, such as coal gas and air or oxygen, the intimate mixing of these in the inlet

arrangements, combined with the turbulence in the cylinder during the compression stroke, result in a fairly homogeneous mixture at the moment of ignition. There are special cases, however, in which such is not the case, and where stratification is aimed at. This result can be obtained to some extent when special provision is made.

The motor car engine using liquid fuel does not, however, require a stratified mixture, but a homogeneous one, as will be seen later on, and in order to obtain this the carburettor should be designed for that end.

Another term which will frequently be used is that of "depression at the orifice," or "head over the orifice," expressed in inches of water. This means that the difference of pressure between that of the atmosphere and that adjacent to the fuel orifice is sufficient to support a column of water the number of inches in height which is expressed. Saturation of air by a vapour occurs when the air is unable to support any more vapour in that form, so that the addition of vapour causes precipitation of the liquid from which the vapour has arisen.

Raising the temperature of the mixture will, however, allow the air to retain a greater percentage of vapour, as will also a reduction of pressure.

Fuel is discussed as containing a certain number of "fractions" or constituents which distil off as the temperature of the fuel is raised. Petroleum spirit consists of many different hydrocarbons, and in specifying any spirit, its final boiling or distillation point is one of the most important factors, together with the percentage of the total quantity of the fuel distilling off at different temperatures.

The "lighter fractions" designate the more volatile benzines of the hexane series when referred to motor spirit, but with reference to crude oil may imply all those constituents distilling below 150° C., which usually comprise commercial motor spirit.

Fuel may be mixed with air in several ways. The first and the oldest form of carburation is by passing the air

through a volume of liquid fuel. On the other hand, the volume of air can be treated by spraying into it a certain quantity of fuel in a more or less finely divided state. There is another form of carburation, which is virtually distillation or evaporation by means of applied heat, and it is quite conceivable that if a volume of air is passed over a liquid, and a higher temperature than the normal is applied to this liquid, the evaporation of the liquid will be accelerated above what it is under ordinary atmospheric conditions. Assuming that the rate of evaporation of the fuel is in proportion to the amount of air passing, and that the air is brought sufficiently near to the surface of the fuel, a satisfactory form of carburation will follow.

It is naturally somewhat difficult, when dealing either with air or with fuel in quantities, to obtain a homogeneous result in the mixture. For this reason it is preferable to treat small quantities as desired ; furthermore, when small quantities of air and fuel are dealt with, there is not so much risk of accident from any involuntary ignition of the explosive mixture in the generating chamber, as is the case where a larger volume is dealt with in a chamber of considerable capacity.

An engine such as is used in the modern motor vehicle is not running under constant demand, and it is therefore preferable to create an explosive mixture in accordance with the demands of the engine, rather than to store up any quantity of explosive mixture to meet any sudden demand which may come upon the engine. In this practice we are more nearly approaching the modern trend in stationary gas engine practice, where a suction producer is fitted, and the suction producer in that case corresponds to the carburettor of an engine, rather than to the gas holder which was previously used when coal gas was employed. We find in a gas set, where the engine sucks directly upon the carburettor, the amount of carburetted air which is drawn in is in direct response to the demands of the engine.

There is probably no part of a modern motor car which has undergone more useful development in recent years than the carburettor. The improvements which have taken place have made it possible to obtain that great range of speeds of engine rotation with which we are all now familiar. Furthermore, these results have been accompanied by other advantages, such as the reduction of petrol consumption, more perfect combustion, the prevention of overheating, and ease of starting.

When we come to investigate how these ends have been obtained, we find that there is no one method or principle which stands out with prominence beyond several others. This fact cannot be disputed, as the result of numerous severe competitive tests show. It may be that, as a result of a series of trials undertaken by one firm of motor car manufacturers, a particular carburettor suits a particular engine somewhat better than other competing carburettors, on all-round results. In another instance we may find again that a different carburettor, working upon an entirely different principle, is more suitable to another class of engine of approximately the same size. It is a particularly interesting fact that such good results as have been obtained recently should have been possible with different instruments.

Let us revert for a moment to the early types of jet carburettors in which the fuel supply to the engine was more or less controlled by the size or number of the jet orifices. This type of instrument, it will be remembered, was fitted with a choke tube, either of one constant diameter located round the jet orifice, or with a conoidal tube, the position of which could be varied with regard to the jet. Taking the first one as exemplified by the old Longuemare, this tube was surrounded by an annulus through which supplementary air was admitted by a hand-controlled device. The arrangement was crude, as it was only capable of giving a correct mixture automatically for the one speed for which the choke tube was suited. As the

speed increased so did the suction, and this latter had to be counteracted by the admission of air from an external source. It will be remembered that in these early devices extra air valves working against springs were often provided to reduce the amount of hand manipulation necessary with such an instrument.

The early Krebs sought to combine the extra air valve with the carburettor by means of air pressure actuating a diaphragm against the resistance of a spring, and in such an arrangement it is possible to design the air ports so that the jet is surrounded by a constant pressure difference with regard to the external atmosphere. A further development of this principle was claimed in the Gillet-Lehmann device, in which a direct connection was made by means of a small pipe between the float chamber and the induction pipe at one or more points. Assuming that the restricting screw or screws were set properly, with a device of this nature it was possible to regulate the pressure difference under which the instrument worked with some degree of nicety. Looking at the matter from the point of view not usually apparent, we may consider that all devices of this nature were forerunners of what are now known as constant vacuum carburettors, and these in detail will be dealt with later.

Again going back to the early days, we can call to mind another line of development, which aimed at restricting the efflux of the liquid fuel as the engine suction increased. Such devices took the form of spirals or bears' poles of metal in the jet orifice. Obviously arrangements of this sort could scarcely be predetermined with regard to their detail so as to give any great accuracy in working, and their effect as regards uniform carburation at all speeds could only be arrived at by means of trial and error. These devices were undoubtedly the forerunners of some of the instruments of to-day, in which the main feature is the variation of jet orifice in accordance with the demands of the engine. The modern form of such an instrument is

designed so that the orifice consists of at least two parts, which rotate relatively to each other, and in which the holes or orifices are circular, segmental, triangular, or any suitable shape, and which give an orifice opening in proportion to the air and throttle opening.

Instruments of this type can be designed previously with a great degree of accuracy, and require very little final adjustment. There are, however, further developments of these instruments working in conjunction with additional air devices, the latter controlled either pneumatically or hydraulically, which in modern designs can be arranged to give excellent results. In such a combination, however, more than one type of adjustment is required, and the instrument immediately becomes liable to derangement and erratic working in the hands of the inexperienced user. Furthermore, the air-controlling arrangement is liable to suffer as the operating mechanism wears, the spring control loses its original liveliness, or the moving parts stick or become loosened.

Now it is very obvious from general principles obtaining in nature, where a body is turned from one state into another, *i.e.*, either from a solid to a liquid state or from a liquid to a gaseous state, a certain amount of interchange of heat must take place in order to effect this change of state, and the amount of heat absorbed is, of course, in proportion to the latent heat of the body. In the case of a liquid such as petroleum spirit, which is of a complex nature, one cannot exactly state what its latent heat of evaporation is, but it is of the order of 160 calories per kilogram, equal to 288 B.Th.U. per pound of fuel evaporated ; that means to say, that every pound of petroleum spirit which is passed through the carburettor requires an addition of heat equal to 288 British thermal units in order to evaporate it so that the resulting mixture shall remain at the same temperature as the incoming air. This heat can be applied in several ways, either by raising the temperature of the incoming air by

drawing that air over, say, the exhaust pipe, or by heating the induction pipe between the mixing chamber of the carburettor and the engine valves. Heat can also be added to the liquid fuel itself before mixing with the air, but such heating has its limitations by reason of the volatility of the fuel and the low boiling point of some of its fractions. It does not really signify how the heat is added as long as the temperature of the resulting mixture remains what is desired. By this latter expression, of course, a great deal depends upon the locality, and the duty which the car has to perform, and theoretically it is more suitable for the temperature of the incoming mixture to be as low as possible consistent with the liquid remaining in the evaporated or suspended state without precipitation.

There is one point in connection with carburation which is very frequently referred to, but about which very little useful data is obtainable. This point is the effect of the inertia of the liquid in the jet and passage leading thereto. In those types of carburettors fitted with a modulating pin, the inertia of the liquid is negligible, as there are more important details than the flow of the fuel which are affected by inertia. Take, for instance, the Stewart instrument: there is bound to be a certain amount of lag in its action as the moving part has considerable mass, and, when the throttle is opened, this mass must respond both against the action of gravity and its own dashpot. When the throttle is closed there is again a certain lag, but owing to the fact that the valve is off its seat there is an area for air-flow considerably greater than the normal. The result is, that owing to the decreased suction very little petrol will be drawn up the centre tube, and the presence of the pin will further baffle the flow of liquid to the centre tube. Conversely, when the throttle is opened rapidly a desirable state of affairs is reached, namely, a large suction is produced at the jet during the time the valve is rising to its normal position, and a correspondingly increased richness of mixture follows. This richness enables the

engine to pick up quickly, owing to the known fact that a rich mixture, within certain limits, produces a more powerful explosion.

So-called constant suction carburettors are not really by any means operating under the conditions indicated by their title, as the suction is continually varying, but not in the manner that it does in the ordinary jet and choke tube instruments. For instance, one may calculate out and find in practice that a certain carburettor will operate normally under a certain depression, and this depression will usually occur when the throttle is almost closed and the engine running slowly. However, if the throttle be open the value of the depression immediately decreases until a condition of stability is reached when the engine is running at a speed corresponding with its throttle opening. It will be found that in practice the depression is not the same as before, and, as the engine speed increases, the difference in pressure inside and outside the carburettor has undergone further slight but perceptible changes, which vary in accordance with the design of the particular carburettor. The changes of depression are most important, as, if the value reaches too low a point, it is practically impossible for the carburettor to pass sufficient petrol through its jet properly to carburate the amount of air passing.

One must bear in mind that although high efficiency is aimed at in the design of a carburettor working under a small depression, there is a certain limiting size of orifice beyond which it is inexpedient to go, on account of the difficulty of getting sufficient petrol through it when the engine demand is high. The author has had several difficulties of this nature quite recently, and it would appear that in practice the experimental feature is borne out with regard to the falling off in the ratio of petrol flow to area of orifice as the area of the orifice increases above the maximum desirable size before referred to.

In the types of carburettors using a modulating pin, one is able to take advantage of two fairly easily controllable

factors, namely, the positively varying jet orifice and the possibility of suiting the air opening to any particular type or size of engine. This latter feature is a most important one when what is known as "high efficiency" work is concerned. The details necessary for the fundamental principles of design of the air aperture will vary with each particular job, and depend, of course, upon valve areas, compression spaces, and so forth, which have a bearing upon the particular results aimed at.

A desirable feature in modern carburettors is that of easy starting, and this is frequently attained by the use of a starting well. This well may consist of a certain volume of liquid, which at other times may be used as a dashpot for the moving element of the carburettor, or, on the other hand, may be a volume of petrol standing in a tube above, or adjacent to, the actual jet orifice.

A good deal is often made of the necessity for the ability to vary a carburettor to suit climatic conditions or those of temperature, and details as to why this becomes necessary are given in a later chapter. The automatic carburettor of the varying jet type is the easiest to alter to suit special conditions, and, in addition to the modulating pin scheme, there is that in which a number of similar jets are uncovered by a predetermined plunger method. Such an instrument is at once one that adapts itself automatically to a wide range of demand, and embodies the necessity for a large area for high speed work, with the concentration of air-flow necessary for starting and slow running. Furthermore, this instrument embodies a combination adjustment which acts throughout its entire range of working in the same proportion, and when the flow of fuel is set for one speed or working position, it remains correct for all other positions.

CHAPTER II

VAPORISATION AND EVAPORATION

It has been pointed out that in changing a body from one state to another, such as from a liquid to a gas, heat is required to be applied, and the amount of such heat in any particular case is the latent heat of evaporation of the liquid.

In the case of water, if we have 1 lb. of this liquid at a temperature of 212° F., and convert the whole of it into steam at the same temperature and without loss of heat, an addition of 966 B.Th.U. will be required. This heat, it will be seen, is 6.35 times the heat required to raise the temperature of the same body of water from 60° F. to boiling point.

Liquid fuels, however, have a lower latent heat of evaporation than water, as will be seen from the following table:—

Table I.—Latent Heat of Evaporation of Liquids.

	B.Th.U. per lb.	Calories per Kilogr.
Water - - - -	966	244
Hexane - - -	210	53
0.700 sp. gr. petrol -	250-288	63-72
Benzol - - -	232	58
Commercial alcohol -	520	130

We will now proceed to consider the characteristic properties of fuels to be dealt with, and this can be done in a more concise manner by means of a few tables. First, taking the petroleum series of hydrocarbons represented by C_nH_{2n+2} :—

TABLE II.—(SOREL).

Name.	Formula.	Boiling Point.	Specific Gravity at Temperature Indicated.
		Degrees C.	Degrees C.
Hexane*	C_6H_{14}	69-71	0.663 at 17
Heptane*	C_7H_{16}	98	0.668 „ 15
Octane normal*	C_8H_{18}	124	0.719 „ 0
Octane isomere*	...	119-120	0.719 „ 17
Nonane*	C_9H_{20}	149.5	0.723 „ 13.5
„ †	C_9H_{20}	135-137	0.742 „ 12
Decane	$C_{10}H_{22}$	158-159	0.736 „ 18
Undecane	$C_{11}H_{24}$	180-182	0.756 „ 16
Dodecane	$C_{12}H_{26}$	214.5	0.755 „ 15
Tredecane	$C_{13}H_{28}$	218-220	0.778 „ 15
Tetradecane	$C_{14}H_{30}$	236-240	0.796
Pentadecane	$C_{15}H_{32}$	258-262	0.809

* Chief constituents of motor spirit.
† And onwards, chief constituents of kerosene.

Next we will consider the distillation of a typical motor spirit:—

TABLE III.—(SOREL).

Tenths.	Temperature.	Specific Gravity.	Substance Collected.
	Deg. Cent.		
1	52	0.649	Pentane and hexane.
2	53	0.647	
3	58	0.653	
4	63	0.678	
5	67	0.666	
6	71	0.673	Hexane and heptane.
7	79	0.686	
8	89	0.698	Heptane and octane.
9	120	0.715	Octane.
1	66	0.655	Pentane.
2	70	0.664	Hexane.
3	77	0.676	Hexane and heptane.
4	84	0.688	
5	90	0.701	
6	101	0.713	
7	112	0.726	Nonane and decane.
8	123	0.814	
9	160	0.749	

TABLE IV.—COMPARING DISTILLATION POINTS OF VARIOUS SPIRITS AND BURNING OILS.

Percentage coming over at the Various Temperatures shown.	Varieties Distilled.						
	Pratt's, Sp. G., .700.	Shell, .717.	Shell "Borneo" Spirit, .753.	Tar Benzol, .878.	Refined Peruvian Spirit, .729.	Rocklight Paraffin, .825.	White Rose Paraffin, .800.
	Deg. Cent.	Deg. Cent.	Deg. Cent.	Deg. Cent.	Deg. Cent.	Deg. Cent.	Deg. Cent.
First drop - - at	43	50	43	50	50	100	76
5 per cent. - - ,,	50	62	59	51.7	57	142	142
10 ,, - - ,,	53	67	70	53	60	152	149
15 ,, - - ,,	55	71	74	54	65.5	160	159
20 ,, - - ,,	63	74	76	56	70.5	163	167
25 ,, - - ,,	71	78	77	59	75	170	175
30 ,, - - ,,	73	79.5	78	72	76	176	181
35 ,, - - ,,	75	82.5	79.7	75	78.5	180	188.5
40 ,, - - ,,	77	85	85	79	82	189	191
45 ,, - - ,,	80	87	91	80.4	83	195	196
50 ,, - - ,,	80	90	94	82	84	200	200
55 ,, - ,,	81	92.5	95	82.7	85.5	210	205
60 ,, - - ,,	90	95	97	83	86.5	217	207
65 ,, - - ,,	100	97	98.1	84.5	87.5	223	210
70 ,, - - ,,	103	101	100	85	89.5	232	219
75 ,, - - ,,	108	104	102	86.7	92	238	228
80 ,, - - ,,	110	108	106	88	94	247	233
85 ,, - - ,,	130	112.7	110	89.1	96	260	242
90 ,, - - ,,	133	121.5	117	90	99	270	252
95 ,, - - ,,	134	140	132	93.8	102	296	258
100 ,, - - ,,	140	154	141	97	107	300	262

TABLE V.—KEROSENE (SOREL).

Tenths.	Temperature.	Specific Gravity.	Substances Collected.
	Deg. Cent.		
1	138 to 177	0.755	Nonane to undecane
2	177 „ 197	0.765	Undecane to dodecane
3	197 „ 212	0.776	Dodecane to tredecane
4	212 „ 236	0.783	Tredecane to tetradecane
5	236 „ 253	0.796	Tetradecane
6	253 „ 274	0.795	Pentadecane and hexadecane

It will thus be seen that the composition of motor fuels of the petroleum series is somewhat complex and does not bear out any definite rule, but that the proportion of the lightest constituents is such that they are sufficient, under ordinary circumstances, to effect a fair proportion of the necessary carburation when the air is cold. As it is better in a good system of carburation to vaporise the liquid completely before introducing it into the engine, the quantity of the air supplied depends both on the composition of the fuel and on its vapour pressure and temperature.

*TABLE VI.—(SOREL).—VAPOUR PRESSURES OF DIFFERENT FUELS IN MM. OF MERCURY (EXPERIMENTAL).

Temperature.	Hexane.	Automobiline.	Motonaphtha.	Benzol.	Kerosene.
Deg. Cent.					
0	45	99	152	27	16
5	58	115	170	36	17
10	74	133	191	45	19
15	95	154	214	61	22
20	119	179	240	77	24
25	154	210	260	96	28
30	184	251	292	120	30
35	228	301	345	156	34
40	276	360	413	188	39
45	335	422	496	224	43
50	401	493	575	271	48
55	482	561	660	326	53
60	567	648	768	390	59

* See also Fig. 10, p. 87.

The latent heat of vaporisation lowers the temperature during carburation, thus lowering the vapour pressure, and external heating must be resorted to in order to convert the suspended particles of fuel into a vapour and prevent their precipitation in liquid form.

The theory of Mr E. Scott Snell is based upon Dalton's classic experiments on mixtures of gas and vapour. The conclusions Dalton came to (which have been found correct except in special circumstances) were:—

(1.) That in a space which contains a liquid and its vapour the liquid will evaporate only until the pressure of its vapour attains a definite value dependent upon temperature only.

(2.) That in a space containing dry air or other gas or gases, a liquid will continue to evaporate until the pressure exerted by its vapour alone is the same as if no air or other gas were present.

(3.) That in any mixture, the total pressure is equal to the sum of the pressures that each constituent would exert if it occupied the space alone.

The last two laws are only true in the case where the liquids are not mutually soluble. When the liquids are completely miscible, as for instance the various constituents of commercial petrol, the sum of the vapour pressures will be less than the sum of the separate vapour pressures, but its value is more easy to determine by direct experiment than to predict from theoretical considerations alone.

Suppose we have 100 cubic metres of air and vapour at 760 mm. pressure and $t°$ C., of which x cubic feet is vapour. The latter *will behave as if* it occupied the whole space alone, *i.e.*, as if it had a pressure due to expanding from x cubic metres at 760 mm. and $t°$ C. to 100 cubic metres at $t°$ C. This pressure would therefore be

$$760 \times \frac{x}{100}.$$

If we know the vapour pressure p at temperature $t°$ C.

(as we often do from vapour-pressure determinations) we have

$$p = 760 \times \frac{x}{100},$$

from which we get

$$x = 100 \times \frac{p}{760}.$$

It follows from the first law that such a mixture is not on the point of condensing part of its vapour unless p is the pressure of the saturated vapour corresponding to that particular temperature. Hence the condition of stability, or otherwise, is known if we know the pressure of the vapour in the mixture and the saturation temperature corresponding to this pressure.

In practice we usually know the composition of a mixture in the form of a certain weight of petrol evaporated into a certain volume of air, hence we require for convenience a formula which will give us the vapour pressure directly from these data.

Mr E. Scott Snell states that the pressure of vapour in any given mixture of fuel vapour and air can be calculated from the formula,

$$p = \frac{760}{1 + V\delta},$$

where p is the vapour pressure in mm. of mercury; where V is the volume of air in cubic metres.

δ is the absolute density, *i.e.*, the weight in grammes of 1 litre of vapour at 0° C. and 760 mm. of mercury pressure.

This formula can be deduced as follows:—

Consider a space of V litres capacity.

Let D be the weight in grm. of 1 litre of gas (in this case air) measured at 0° C. and 760 mm.

Let δ be the weight in grm. of 1 litre of vapour measured at 0° C. and 760 mm.

Let H be the pressure of the gas (in this case the pressure of the atmosphere) in mm. of mercury.

Let p be pressure in mm. of mercury of the vapour at

the temperature t° C. of the mixture, and a the coefficient of expansion of gas and vapour.

Then the weight of V litres of air

$$=\frac{\text{VD}(\text{H}-p)}{(1+at)760}\text{ grm.,}$$

and the weight of V litres of vapour

$$=\frac{\text{V}p\delta}{(1+at)760}\text{ grm.}$$

Dividing the second expression by the first, we get

$$1\text{ grm. }\left(=\frac{1}{\text{D}}\text{ litres}\right)\text{ absorbs }\frac{p\delta}{\text{D}(\text{H}-p)}\text{ grm. of vapour.}$$

Hence 1 litre absorbs $\frac{p\delta}{\text{H}-p}$ grm. of vapour, or V cubic metres absorb $\frac{\text{V}p\delta}{\text{H}-p}$ kg. of vapour.

From which we have, if 1 kg. of vapour is absorbed in V cubic metres of air,

$$p=\frac{\text{H}}{1+\text{V}\delta};$$

or expressed in English units,

$$p=\frac{760}{1+\frac{\text{V}}{\text{F}}}$$

where V = cubic ft. of air evaporating one gallon of spirit and F = cubic ft. of vapour given by one gallon of the spirit.

For example, for the complete combustion of hexane as given by the formula $2C_6H_{14}+19O_2=12CO_2+14H_2O$:—

2×86 kg. of spirit require $19\times 22.4\times 4.81$ cubic metres of air at 0° C. and 760 mm., *i.e.*, 11.9 cubic metres of air per kg. of spirit. The density of hexane is

$$\frac{86}{22.4}=3.84\text{ kg. per cubic metre.}$$

From the equation we get

$$p = \frac{760}{1 + 11.9 \times 3.84} = 16.3 \text{ mm.}$$

and a reference to p. 19 will show that such a mixture should not deposit any vapour until a temperature of -17.7° C. is reached.

As we often want to know what is the percentage composition of a mixture formed by evaporating a certain weight of petrol into a certain volume of air the following formula may be of value :—

$$\text{Vols. per cent.} = \frac{100}{1 + v\delta};$$

or in English units with the same notation as before,

$$\text{Vols. per cent.} = \frac{100}{1 + \frac{V}{F}}.$$

The vapour pressures of complex fuels depend chiefly upon that of their most volatile constituents, even though the proportion of these constituents to the total mass of the fuel is small. When air is admitted to the presence of such fuels, selective evaporation takes place, *i.e.*, the more volatile are at first taken up, leaving the heavier fractions behind. When fuel is injected or sprayed into an air stream, selection undoubtedly takes place, and this affects the homogeneity of the mixture, which will be referred to later on.

Sir Boverton Redwood gives the following figures showing the proportion of hydrocarbon vapour which air will take up, but these vary with the volatility of the fuel, and the pressure, humidity, and temperature of the atmosphere. For instance, dry air will take up the following quantities of vapour from petrol having a sp. gr. = 0.650 :—

10.7	per cent. by volume	at	32° F.
17.5	,,	,,	50° F.
27	,,	,,	68° F.

before the air is saturated. These percentages are equivalent to

1 vol. vapour to 5.7 of air at 50° F.
1 ,, ,, 3.7 ,, 68° F.,

showing that a small increase in the temperature largely increases the percentage of petrol vapour, which can be retained by the air.

Petrol of a sp. gr. 0.700 containing 83.72 per cent. C and 16.28 per cent. H has a vapour density of 0.24 lb. per cubic foot at atmospheric pressure when at a temperature of 32° F., or nearly three times the density of air.

In another form the amount of liquid fuel which can be absorbed by 100 vols. of air at a temperature of 60° F. varies with the density of liquid as follows:—

Specific Gravity of Liquid Fuel.	Percentage of Liquid to Air by Volume.
0.639	0.59
0.679	0.18
0.700	0.17

When air is allowed to bubble through light motor spirit that is frequently replenished, hexane principally is carried off due to selective evaporation, and assuming that hexane only is carried off, 100 litres of dry air at 10° C. and 760 mm. pressure of mercury takes up the following quantities at different temperatures:—

TABLE VII.—(SOREL).

Temperature.		Grammes of Hexane Vaporised.
Centigrade.	Fahrenheit.	
12.2	54	29.44
14.8	59	30.63
16	61	31.32
18	64	32.50
20	68	35.37
22	72	36.10
24	75	37.74

TABLE VIII.—(BAILLIE).*

Fuel.	Minimum Temperature at which Fuel can exist as a Vapour. °C. Correct Amount of Air.	Minimum Temperature at which Fuel can exist as a Vapour. °C. 20 per cent. less Air.	Formula.	Drop of Temperature due to Evaporation in Correct Amount of Air. °C.	Density at 15° C.	Drop of Temperature due to Evaporation. 20 per cent. less Air.	Boiling Point. °C.	Lower Calorific Value per Litre.
Hexane	−17.7	−14.2	C_6H_{14}	19.0	0.674	23.3	68.5	7,155
Heptane	3.6	7.3	C_7H_{16}	17.9	0.688	23.4	98.0	7,380
Octane	19.0	22.9	C_8H_{18}	17.2	0.719	21.5	120.0	7,560
Nonane	...	...	C_9H_{20}	...	0.740	...	136.0	7,900
Decane	42.0	46.1	$C_{10}H_{22}$	14.8	0.738	18.5	160.0	8,060
Benzene	−4.3	−0.7	C_6H_6	32.2	0.884	47.3	80.4	9,690
Ethyl alcohol	23.3	26.5	C_2H_6	76.3	0.794	95.5	78.3	5,270

From the above table we see that motor spirit of average composition, in which only a small percentage of hexane is present, cannot exist in the form of vapour at a temperature below the freezing point of water, and that the denser the fuel, when of the petroleum series, the higher must be the temperature of the air. We also see that benzene or benzol should theoretically vaporise at temperatures as low as the heavier petrols, and remain as vapour at temperatures even below the freezing point of water. This matter is further referred to on p. 149.

Furthermore, we see from Table VI., and Fig. 10 (p. 87), that the low vapour pressure of benzol precludes its use for many industrial purposes, such as air-gas lighting, for which it otherwise would be admirably suited.

* See also Appendix

CHAPTER III

LIMITS OF COMBUSTION—AIR AND HEAT REQUIRED

IN the case of an ordinary mixture of hydrocarbon vapour and air there are two limits, an upper and a lower, between which such a mixture will be combustible under normal conditions. The completeness of combustion depends upon the correct proportioning of air to fuel and whereas the fuel may be in excess and CO be formed as a product of combustion, if air be in excess the exhaust gases will show O_2 to be present. Under the same conditions of temperature and pressure the mixture is non-flammable outside certain limits, but it depends upon the temperature and pressure and their variations, to which the explosive mixture is submitted, as well as upon its initial composition, as to where these limits will be found. If the mixture is homogeneous, combustion will be complete within definite limits, whilst outside them either the mixture will be non-flammable or the combustion will be incomplete.

If combustion takes place in a long tube, and the combining gases are slow-burning, such as CO and O, and the ignition takes place at one end of the tube, the propagation of the flame is slow and easily followed by the eye.

If, however, a jet of flame from the same mixture be projected through the entire mass of the mixture, combustion is complete and rapid. This experiment shows that rapidity of the propagation of the flame can be produced by arranging the ignition in a pocket in such a manner that the richer gas, say over the inlet valve upon

ignition, strikes a flame across the combustion chamber, thus causing turbulence and accelerating combustion.

Now we will consider an example of the combustion of methane, or natural gas and air, and Coquillion found that 1 vol. of CH_4 and 5 of air were non-explosive when subjected to an electric spark, a 1 to 6 mixture gave the inferior explosive limit due to insufficient air. When the proportion of air was increased by 7 to 10 to 1 vol. of methane the maximum pressures were reached. As the air was increased so as to be 15 vols. to 1 of methane the explosion weakened off, till at a 16 to 1 mixture the upper limit was reached when no ignition occurred. These mixtures were only at atmospheric pressure, and the upper limit can be further extended as the initial pressure is increased. One of the principal objects of compression is to enable a weak mixture to be fired, which under atmospheric pressure is non-explosive. Dilution of a mixture either by air or inert gas results in the excess of such gas absorbing part of the liberated heat of combustion, and so fixes the limit between explosion and non-explosion, and also the line between the zone of non-explosion and apparent equilibrium.

Sorel's experiments with pure benzene, the coal-tar product, were made at atmospheric pressure and at a temperature of 100° C. Theoretically requiring 10.71 litres of dry air at 10° C. per grm. of benzene for complete combustion, the upper limit through excess of air was reached when the air introduced was 2.2 times the theoretical quantity. The inferior limit through excess of fuel was very low, as combustion continued when the air was cut down to 0.27 times the theoretical amount.

Experiments with light motor spirit showed that the upper limit was reached with 1.84 times the theoretical amount of air, whilst the lower limit was between 0.4 and 0.5, and with alcohol mixtures the upper limits were of the order of 1.5 and the lower 0.4.

Generally with all commercial motor fuels the superior

limits of combustibility varied very little, and the lower limits still less, except for pure benzene.

The latter fuel, as benzol, may therefore be expected to have a somewhat wider explosive range than ordinary motor spirit, as it can burn rather more air, and does not fail to fire when the mixture is enriched to a greater degree than petroleum spirit would permit.

The following tables of Sorel's experiments show the velocity and colour of the flame with various mixture strengths, and the author has observed similar flame colours in a suitable apparatus attached to the cylinder of an experimental engine in Dr Watson's laboratory in South Kensington. In his engine the mixture strength can be varied, also the point during combustion at which the observation is made.

Table IX.—Petroleum Spirit.

Quantity of Vapour carried by 1 litre of Dry Air at 10° C. and 760 mm. Pressure.	Ratio of Air Introduced to Air necessary for Combustion.	Maximum Observed Velocity. Metres per Second.	Remarks.
0.038	2.19	0.00	Incombustible.
0.044	1.85	0.30	Slightly combustible.
0.048	1.76	0.88	Blue flame.
0.056	1.49	0.94	,, ,,
0.061	1.35	1.10	,, ,,
0.075	1.11	$>$0.38	Blue and green flame.
0.079	1.08	0.56	Green flame.
0.082	1.01	0.53	Green and red flame.
0.101	0.83	0.05	Green flame.
0.122	0.68	0.00	Incombustible.
Pure Benzene.			
0.037	2.30	0.00	Incombustible.
0.046	1.94	1.13	Blue flame.
0.050	1.86	1.30	,, ,,
0.057	1.63	1.29	,, ,,
0.085	1.09	1.12	,, ,,
0.094	0.98	1.04	,, ,,
0.104	0.89	...	Green flame.
0.124	0.76	0.53	Green and red flame.
0.211	0.44	0.25	Red flame.

Quantity of Air Required.—When considering the amount of air required to form an explosive mixture, this may be done in several ways, either as a ratio of weight of air to weight of fuel, or as a ratio of the volumes of the two substances, or as a proportion of air to saturated vapour of the fuel. Care must therefore be taken to avoid confusion. As a rough indication we may take, in round figures, that the 1 vol. of petroleum spirit requires 10,000 vols. of air introduced through the carburettor to give complete combustion. In another form we may state that 1 lb. of liquid fuel requires approximately 15 lbs. of air for its combustion reduced to atmospheric temperature and pressure.

Consumption figures for various engines and carburettor arrangements show that this latter figure may vary from 11 to 1 as the richest limit, to 18 or 19 to 1 as the weakest. The ratio of 18 to 1, if properly carburetted, will give the highest thermal efficiency combined with power production.

A richer mixture will give a slight increase of power in many carburettors, but at the expense of thermal efficiency.

In order to find the correct proportion of air to fuel, the equation representing combustion must be considered, and Mr E. Scott Snell makes the following calculation in order to give definite values for the various constituents of petroleum spirit.

Combustion may be represented as taking place according to the formula (for hexane)—

$$2.C_6H_{14} + 19O_2 = 12\ CO_2 + 14\ H_2O.$$

i.e., 2 vols. of vapour require 19 vols. of oxygen contained in $19 \times 4.81 = 91.3$ vols. of air;

Or, 100 vols. of mixture contain 2.14 per cent. vapour.

By further calculation we can arrive at the following table, showing the proportions for those members of the petroleum group usually met with in automobile practice:—

TABLE X.

Fuel.	Formula.	Sp. Gr.	Ideal Mixture.
Pentane -	C_5H_{12}	0.626 to 0.640	2.53 per cent.
Hexane -	C_6H_{14}	0.663 to 0.680	2.14 ,,
Heptane -	C_7H_{16}	0.688 to 0.700	1.86 ,,
Octane - -	C_8H_{18}	0.719	1.64 ,,
Nonane -	C_9H_{20}	0.728 to 0.742	1.46 ,,

It will be seen that as the specific gravity of the fuel increases a greater proportion of air is required for combustion. The proportions given are those required to give the greatest explosive effort when the mixture is fired in a confined space.

We will now proceed to make an elementary calculation to show how the correct amount of air can be arrived at, knowing the chemical composition of the fuel.

Taking a Borneo spirit of 91 per cent. carbon and 9 per cent. hydrogen, 1 lb. carbon requires 11.6 lbs. of air for its complete combustion—

$$\therefore 0.91 \times 11.6 = 10.5 \text{ lbs. of air for the C.}$$

1 lb. hydrogen requires 34.8 lbs. for its complete combustion—

$$\therefore 0.09 \times 34.8 = 3.14 \text{ lbs. of air for the H.}$$

Hence, theoretically, the total air required = 13.64 lbs., which at 62° F. = 182 cub. ft. at atmospheric pressure. In practice, we find the excess of air admitted greatly dilutes this mixture, and that instead of a mixture containing 1.8 per cent. of petrol vapour, the vapour is diluted with 60 or 70 times its own volume of air, *i.e.*, the percentage of petrol is only 1.6 or 1.43.

The investigations of Sir B. Redwood upon the limits of explosion of mixtures of petrol vapour and air show that when using a petrol of 0.720 sp. gr., and firing the mixture in a closed vessel by means of a naked flame,

the most explosive mixture consisted of 1.86 per cent. of petrol vapour. With a petrol of 0.680 sp. gr. these figures become 2.5 per cent., as is shown in the following table:—

TABLE XI.

SPECIFIC GRAVITY OF PETROL 0.680, GIVING 190 TO 260 TIMES ITS OWN VOLUME OF SATURATED VAPOUR.

No ignition with - -	1.075	per cent.	by volume	of petrol vapour.
Silent burning with -	1.345	,,	,,	,,
Sharp explosion with -	2.017	,,	,,	,,
Violent explosion with -	2.352	,,	,,	,,
Less violent explosion with	3.362	,,	,,	,,
Burning and roaring -	4.034	,,	,,	,,
Burning silently - -	5.379	,,	,,	,,

The most violent explosion occurred when 12.25 vols. of liquid were mixed with 100,000 vols. of air.

These experiments were conducted without a previous compression of the mixture, and it is chiefly owing to this compression in an engine cylinder that such weak mixtures as are used in modern practice can be made to explode.

The following interesting figures are given by Eitner as the proportions of various gases to air corresponding with the explosive limits of the mixtures:—

TABLE XII.

Combustible Gas at 60° F.	Lower Explosive Limit.	Upper Explosive Limit.
Hydrogen - - - -	9.45	66.40
Water gas - - - -	12.40	66.75
Acetylene - - - -	3.35	52.30
Coal gas - - - - -	7.90	19.10
Methane - - - - -	6.10	12.80
Benzene vapour - - -	2.65	6.50
Benzoline vapour - - -	2.40	4.90
Alcohol - - - - -	8.00	12.00
Ether - - - - -	2.00	8.00
Petrol - - - - -	2.00	5.00

An insufficiency of fuel at the time of ignition will cause failure to ignite, but after the moment of ignition, air can be added to the burning mixture with satisfactory results, causing economy in working in some instances. The stationary engine made by the Westinghouse Brake Co. works on this principle, and uses kerosene as its fuel. The Diesel engine also works with an excess of air, but its principle is different from that under discussion, as no sudden rise of temperature takes place.

An excess of fuel, on the other hand, is generally due to lack of homogeneity in the mixture which the carburettor produces, and in order to eliminate weak zones in the mixture which might be adjacent to the ignition plug, the whole of the mixture is sometimes enriched so that its weakest zones are of normal constituency.

It is essential that in a gas or vapour engine the working fluid should be supplied to the engine in as homogeneous a form as possible, in order that the rate of propagation of the flame through the mixture may be uniform and of a maximum velocity. Particularly is this necessary in high speed engines, where the flame velocity has to be very great in order that the pressure should, as it were, keep up with the piston. It has been found in practice that where lack of homogeneity in the mixture occurs, the expansion of the burning gases is erratic, and produces humps on the expansion curve of the indicator card. Sometimes these humps have been rather difficult to explain, but we may take it for a fact that they are due to variations in the stages of combustion of a liquid fuel due to the lack of homogeneity in it. We do not find that these humps occur in gas engine practice to any marked extent, and where a hump has occurred it has been of a fairly regular formation, and may be due in some instances to the interchange of heat between the burning mixture and the cylinder walls. We find, however, in an engine burning liquid fuel, that in some cases the hump is most marked, and one of the points which the author raised in connection with a

recent discussion was that their regular formation on the indicator card was probably due to the lack of homogeneity in the explosive mixture which was produced by the particular carburettor fitted to the engine.

In further confirmation of this theory, it was pointed out that the proportion of air to fuel was abnormally small for a high-class carburettor under testing conditions, and it is very probable that the mixture in this case was too rich on account of lack of homogeneity. Certain portions of the mixture were abnormally rich, in order that the other portion of the mixture should have the correct ratio of constituents in order to complete the ignition.

It is difficult for our minds to consider the smallness of a molecule, but in the limit we may take it that an ordinary perfect gas is body divided into its finest possible particles. In a hydrocarbon mixture, gas with air, it is obvious that in order that the rapidity of the combustion should be ensured, the hydrocarbon must be divided into the finest possible particles, so that each molecule of hydrocarbon can combine at the critical moment with its necessary molecules of oxygen.

One of the objects of the carburettor is to break up the fuel into these finely divided particles, in the limit, into a gas or mist, and any variation from this idea is a step in the downward direction in carburation.

We come, therefore, to the question of surface to volume ratio, and it is a well-known fact that a sphere presents the smallest surface to volume ratio of any known shape. Now if one studies the formation which a liquid takes in issuing from an orifice, or in moving through space or the atmosphere, one of course notices that the spherical form is always taken by the particles. We have, therefore, as a peculiarity of nature, to deal with liquid which naturally presents to us the greatest difficulty with regard to its presentation of surface for the carburetting process. We ought, therefore, to divide these globules into their largest

number possible, in order to present a maximum surface of fuel from which evaporation can take place. A simple law of mathematics shows us that the relations between the volumes of different bodies are to one another as the cubes of their diameters, so that if we have a globule whose diameter is 1 in any particular units, and another globule whose diameter is 2, the latter will contain 8 times as much matter as the former. The importance of fine subdivision of the fuel in the carburettor itself is thus emphasised, as it is obvious that those particles of hydrocarbon at the centre of a globule cannot combine with the oxygen of the air until they are actually in contact with it. This means that the time element is proportional to the size of the globule, and where rapid carburation takes place, either the subdivision of the fuel must be very fine, or an excess of fuel must be permitted to pass through the carburettor, the external portions of each globule only being correctly mixed with its necessary amount of oxygen.

In this latter case either the fuel passes as liquid into the engine cylinders and is there burnt, causing distortions of the true expansion curve, or it passes away unburnt to the exhaust. It is the author's contention that heavy fuel consumption is due to the lack of sufficient subdivision of the particles of fuel in the carburettors themselves. Furthermore, in many cases, although this subdivision or spraying may take place in the first instance, its effect is nullified by obstacles presented to its path through the carburettor and inlet pipe on the way to the engine.

Such a state of affairs undoubtedly takes place whenever a change of direction in the flow-path occurs, and it can only be minimised by the application of heat.

A controversial point here arises, as to whether it is better to allow the mixture to enter the engine at practically atmospheric temperature, thereby getting the greatest weight of charge into the cylinders every time at full

throttle opening, or to allow the mixture to reach a higher temperature, at which it is perfectly carburetted, although the weight per charge is less.

The author is certainly of opinion that the latter is the better state of affairs, as although the weight of charge may be slightly less (due to its rise of temperature), the more homogeneous mixture in the latter case will burn far more efficiently. By this is meant that the rate of propagation of the flame through a homogeneous mixture is more rapid and regular than is the case where the surface to volume ratio of the incoming fuel varies from one location to another.

Heat Required.—It has already been pointed out that in order to change the state of a body from a liquid to a gas, heat must be applied, and this in amount must be equal to the latent heat or evaporation of the fuel.

Let us consider first the lighter constituents of petroleum spirit, say hexane, whose specific heat is 0.50, with a latent heat of evaporation of 117 calories per kilogram.

This fraction is mixed with other heavier fractions, so that probably the average latent heat of the whole of the spirit is of the order of 160 calories per kilogram.

We will, therefore, consider a fuel whose latent heat is 160 calories per kilogram, and whose specific heat is 0.50, and it is necessary to supply these 160 calories to every kilogram of fuel vaporised, if the resulting temperature of the mixture is to be the same as that of the surrounding atmosphere.

If air heating is employed we must first take into account the specific heat of the air, and that, as compared with water, is 0.2375. In other words, 0.2375 of a thermal unit will raise the temperature of the air through 1° in any scale whether English or C.G.S. units are taken.

Supposing now that the theoretical quantity of air is

supplied, *i.e.*, fifteen times the weight of the fuel, or 15 kg. per kilogram of fuel, we have as the result :—

Spirit, latent heat	-	0.50
Air, 15×0.2375	-	3.56
Total	-	4.06

The quotient $\frac{160}{4.06} = 39.4°$ C., as the rise in temperature of the air entering the carburettor, *i.e.*, 71° F.

If a lighter spirit, such as hexane, is used, these figures become 28° C. or 50.5° F. Now the Table VIII. shown on p. 19 shows that, say, heptane can only exist as vapour at a temperature of 3.6° C., so we must add the value just found, *i.e.*, $39.4 + 3.6 = 43°$ C. should be the minimum initial temperature of the air in order to effect complete vaporisation in the carburettor.

If the engine speed is higher, so that the fuel does not have sufficient time to absorb the necessary heat in the carburettor and induction pipe, the temperature of the air should be higher.

We will now proceed to discuss how an excess of air, when working, allows of a lower working temperature to be maintained in a homogeneous mixture such as hexane.

This fraction, as seen in Table VIII. just referred to, will remain in vapour form with the correct amount of air at a temperature as low as $-17.7°$ C. (Sorel), and complete evaporation would only remain possible if the initial temperature of the air were $28 - 17.7 = 10.3°$ C.

If, however, about 1.3 times the theoretical amount of air be present, or 19.9 kg. of air per kilogram of hexane, the minimum temperature of saturation is $-24°$ C., and the thermal capacity of the mixture of air and hexane is :—

Hexane, latent heat	-	0.50
Air, 19.9×0.2375	-	4.73
Total	-	5.23

The temperature drop is, therefore, $\frac{117}{5.23} = 22.4^\circ$ C., and the minimum temperature for the incoming air is $22.4 - 24 = -1.6^\circ$ C.

Now if we consider the temperatures at which mixtures of heptane and air will remain stable, we find that for a correct mixture the minimum temperature is 3.6° C., but if the mixture is enriched with 20 per cent. of fuel, the temperature can be reduced to practically zero C., *i.e.*, 32° F. The richer the mixture the lower the temperature, but we may take it that at the freezing point of water we have practically the limit at which a carburettor will work.

Now we come to the explanation of a fact which is not generally understood, viz., why it is that a fixed carburettor, or carburettor in which the relations between the air-flow and the fuel-flow are pre-determined, does not always work well until it is warmed up, and that it is sometimes necessary to flood the carburettor before the engine will start. This is entirely due to the complex nature of the fuel, and to the absence of sufficient heat supply to effect carburation. From the previous figures, in which it was pointed out carburation would not remain stable unless the mixture was abnormally rich, it will be obvious that in order to obtain carburation, and maintain it when the temperature is low, it is necessary to do one of two things—either to make the mixture abnormally rich or to ignore the heavier fractions of the fuel, and carburate only with the lighter one, allowing the heavier ones in the first instance to be carried through the engine unconsumed.

It is often pointed out that the so-called automatic carburettors are difficult to start, and will not work until properly warmed, and that it is absolutely essential for their working that they be either water-jacketed or heat-jacketed in some way. This is perfectly true, as if in a properly designed carburettor of that type the fuel is correctly proportioned for running under normal condi-

tions, when the conditions are abnormal, the air supply must be shut down or the fuel supply temporarily increased. It may occur to the reader that there is one other way of adding heat to effect carburation, viz., adding it to the liquid before it is mixed with the air, but on consideration it will be obvious that as the relative weight of liquid to air is small, of the order of one to fifteen, that although the specific heat of the liquid is very considerable as compared with that of air, it would be impossible to add sufficient heat to the liquid in order to supply the necessary thermal units required for the latent heat of evaporation. Now the specific heat of the liquid is only about three times that of the air, and as there is about fifteen times as much air as fuel by weight, it is quite obvious that it would be necessary to raise the temperature of the liquid through say five times the range that it is necessary when dealing with the air. This is quite impossible, as the lighter fractions of the fuel begin to come off at a fairly low temperature. Some carburettors certainly do heat the liquid fuel, but not to the extent here indicated; and furthermore, it must always be borne in mind that in those types in which the fuel is heated there is another effect, viz., that of reduction of the viscosity of the fuel, so that a greater quantity passes through the same sized orifice under similar conditions than would be the case were the fuel used cold.

A hot-water jacket in a carburettor, in addition to heating the fuel, does of course heat the incoming air, but it has been found in modern practice that an extension of the hot-water jacket is really necessary, and the jacket is therefore carried a considerable distance along the induction pipe.

As showing the effect of temperature upon the viscosity of a certain brand of motor spirit, the author's tests, made some time ago, show the following times taken for a sample quantity to pass through the instrument :—

TABLE XIII.—EFFECTS OF TEMPERATURE UPON VISCOSITY.

Head over orifice = 60 *mm.*

Tests of sample quantity through instrument.

	Fuel: "Anglo 0.760" Spirit.	Petroleum Distillate between 150° and 300° C.
Temperature °F.	Time taken in seconds.	Time taken in seconds.
58	270	400
75	255	390
90	220	375
110	180	...
120	165	...
135	150	...

In the above table the sample was a volumetric one, and not measured by weight, and it will be noticed that as the temperature was raised the fuel became less viscous, and a less period of time was occupied in passing through the orifice.

Simultaneously with the decrease in viscosity we have a decrease in specific gravity, which in other words signifies that a less weight of fuel is contained in the volumetric sample when hot than when cold.

If by any means one could arrange that the fuel passage was so shaped with regard to its frictional properties that these two variables coincided, then we should have a flow of constant weight of fuel at all ordinary working temperatures. This does not, however, occur in practice, as when the orifice is of the usual shape the viscosity decreases more rapidly than the specific gravity, so that when the fuel is warm a greater weight passes through the orifice in unit time than when the fuel is cold. This matter is further discussed in Chapter V., dealing with the flow of fuel through small orifices.

The following table shows the increase in the weight of any one distillate that will pass through a small orifice,

as its temperature is raised, and also the decrease in fuel-flow as a distillate of a heavier specific gravity is substituted.

It will also be noticed that it is not really necessary to increase the size of the air aperture when using a heavier fuel, as the viscosity of that fuel retards its rate of flow.*

TABLE XIV.—THE WEIGHT IN GRAMMES OF VARIOUS DISTILLATES FLOWING THROUGH A LONG TUBE OF SMALL DIAMETER UNDER THE SAME PRESSURE.

Petrol. Sp. Gr.	Boiling Point. Deg. Cent.	Temperature Degrees Centigrade.			
		10	15	20	25
0.700	12-134	125.5	128.5	131.5	134.5
0.725	70-134	90	97.6	104	111
0.755	125-196	68.5	71.5	75	79.5

This matter is discussed more fully and the table amplified in Chapter V.

TABLE XV.—VISCOSITY $= \eta$ (WATSON).

Fuel.	Density at 15° C.	Viscosity in C.G.S. units $\frac{\text{dyne sec.}}{\text{cm.}^2}$		
		5° C.	15° C.	25° C.
Bowley's special -	0.684	0.00380	0.00352	0.00332
Carless - - -	0.704	0.00406	0.00380	0.00359
Express - - -	0.707	0.00445	0.00420	0.00398
Pratt - - -	0.719	0.00445	0.00420	0.00398
Carburine - -	0.720	0.00450	0.00421	0.00400
Shell - - -	0.721	0.00454	0.00421	0.00400
Benzol - - -	0.846	0.00609	0.00572	0.00539
0.760 Shell - -	0.767	0.00534	0.00498	0.00472
Hexane - - -	0.680	0.00376	0.00342	0.00319

* It is interesting to compare these results with those of the same authority on p. 53.

The weight of a liquid of density D which flows on t seconds through a tube of radius r cm. and length l cm., when the length is great as compared with the diameter.

H = the head in cm. of the liquid over the orifice.

η = the viscosity of the liquid.

g = the acceleration of gravity = 981 cm. per sec. per sec.

W = the weight of the liquid in grammes.

$$W = \frac{\pi g D^2 H r^4 t}{8 l \eta}.$$

The author's figures for variation in the specific gravity due to a rise in temperature of the liquid are as follows :—

TABLE XVI.—FUEL TESTED: "ANGLO 0.760."

Temperature in ° F.	Specific Gravity.	Temperature in ° F.	Specific Gravity.
54	0.732	81	0.720
60	0.730	86	0.718
65	0.728	90	0.715
70	0.725	95	0.713
75	0.723		
THEORETICAL.			
100	0.710	120	0.700
110	0.705	130	0.695

It will be seen that the decrease in the specific gravity is not very material, and would in itself only tend to increase the head of petrol by allowing the float to sink deeper into the liquid, retarding its action on the valve which it controls. This retardation means that the petrol would stand at a slightly higher level in the jet, and, in cases where the petrol level is set high, it might cause flooding.

CHAPTER IV

INLET PIPES AND INERTIA

WE will first set down the definition of the word "inertia" so that we may be quite clear upon this point. Inertia is that property of a body by virtue of which it tends to continue in a state of rest or motion, in which it may be placed, until acted on by some force.

Of all the details of a motor car engine, the carburettor and the carburetting system is most sensitive to the question of inertia, for the reason that conditions are continually and rapidly changing, and that the masses of air and fuel which are dealt with are subject to inertia the whole time during which the engine is working. Were an engine working at a constant load and speed throughout the whole time, the question of inertia would not come in, but as this is not the case, we will briefly consider the effect of inertia, both of the air and fuel, and of the moving parts where an automatic carburettor is concerned.

Newton's second law of motion states that "Uniform acceleration is produced by any constant force, the latter being measured by the increase of momentum it produces."

The force producing an acceleration $= \frac{W}{g} \times F$, where W is the weight of the body, g is the acceleration of gravity, and F the acceleration produced.

The final velocity of the body $V = F \times t$, where $t =$ the time during which the acceleration acts.

Every body has an inherent quality or inertia by which it tends to resist a change of velocity, and the kinetic energy of such a body in motion $= \frac{MV^2}{2}$, where M is the mass of the body.

When we compare, firstly, the masses and weights of the two bodies, petroleum spirit and air, we find that a cubic foot of spirit weighs, say, 45 lbs. if its specific gravity is 0.720, and that a cubic foot of air weighs as follows :—

TABLE XVII.—THE PROPERTIES OF AIR.

Temperature, Fahrenheit.	Volume at Atmospheric Pressure.		Density in Pounds per Cubic Foot at Atmospheric Pressure.
	Cubic Feet per Pound.	Comparative Volume.	
0	11.583	0.881	0.0863
32	12.387	0.943	0.0807
40	12.587	0.958	0.0794
50	12.840	0.977	0.0778
62	13.141	1.000	0.0761
70	13.342	1.015	0.0749
80	13.593	1.034	0.0735
90	13.845	1.054	0.0722
100	14.096	1.073	0.0709
110	14.344	1.092	0.0697
120	14.592	1.111	0.0685
130	14.846	1.130	0.0673
140	15.100	1.149	0.0662
150	15.351	1.168	0.0651
160	15.603	1.187	0.0640

Air expands $\frac{1}{491}$ of its volume at 32° F. for every increase in temperature of 1° F., and its volume varies inversely as the pressure.

The volume of 1 lb. of air at 32° F. = 12.387 cub. ft., and at any other temperature and pressure its weight in pounds per cubic foot

$$W = \frac{1.325 \times B}{459.2 + T},$$

where B = the height of the barometer in inches of mercury.

T = temperature in degrees F.

1.325 = the weight in pounds of 459.2 cub. ft. of air at 0° F. and one inch barometric pressure.

We find, therefore, that the ratio of the mass of a cubic foot of fuel to that of air is of the order of $\frac{45}{0.0807} = 558$ times as great.

The smaller the quantity of fuel acted upon by a change of engine suction the smaller will be the inertia, but the velocity of the stream is of great importance, as the momentum varies as the square of that velocity.

For these reasons it is advisable to have the orifice in the jet tube of as little capacity as possible, and to keep the velocity of the fuel through that passage low in cases where inertia effects are likely to be of moment.

In a carburettor system only small quantities of fuel and air are acted upon, and the dimensions of the orifices can be so arranged that inertia factors scarcely come into consideration except at slow engine speeds.

So far as the air is concerned, the effect of lag of flow on account of inertia is shown by Fig. 2; but the lag of fuel-flow may be more pronounced, thus giving a weak mixture at first, to be followed by a rich mixture when the air-flow is retarded. The air enters the mixing chamber more readily than the fuel, but when the throttle is closed there is always the tendency for the fuel to continue flowing unless a suitable damping device is employed.

It is, however, possible to design the passages of such small dimensions, and to arrange the friction of the orifices to be so high, that inertia can almost be damped out. High jet friction is, therefore, one of the means of counteracting the inertia of the fuel, and this can be arrived at by making fuel orifices many in number, by giving either a very small unobstructed hole for the fuel supply, or a hole of larger dimensions in which some medium is interposed for producing high jet friction.

The author has had the opportunity of discussing the question of inertia with Mr A. G. Ionides, the designer of the Polyrhoe carburettor, whose opinion upon the subject is as follows:—

"When the throttle is closed there is a steady, or nearly steady, flow through the carburettor. Under this condition a certain ratio of jet area to choke area may give what is wanted. If now the throttle be opened, with the engine loaded to run slowly, the flow through the throat of the carburettor becomes fluctuating. The velocity of the air

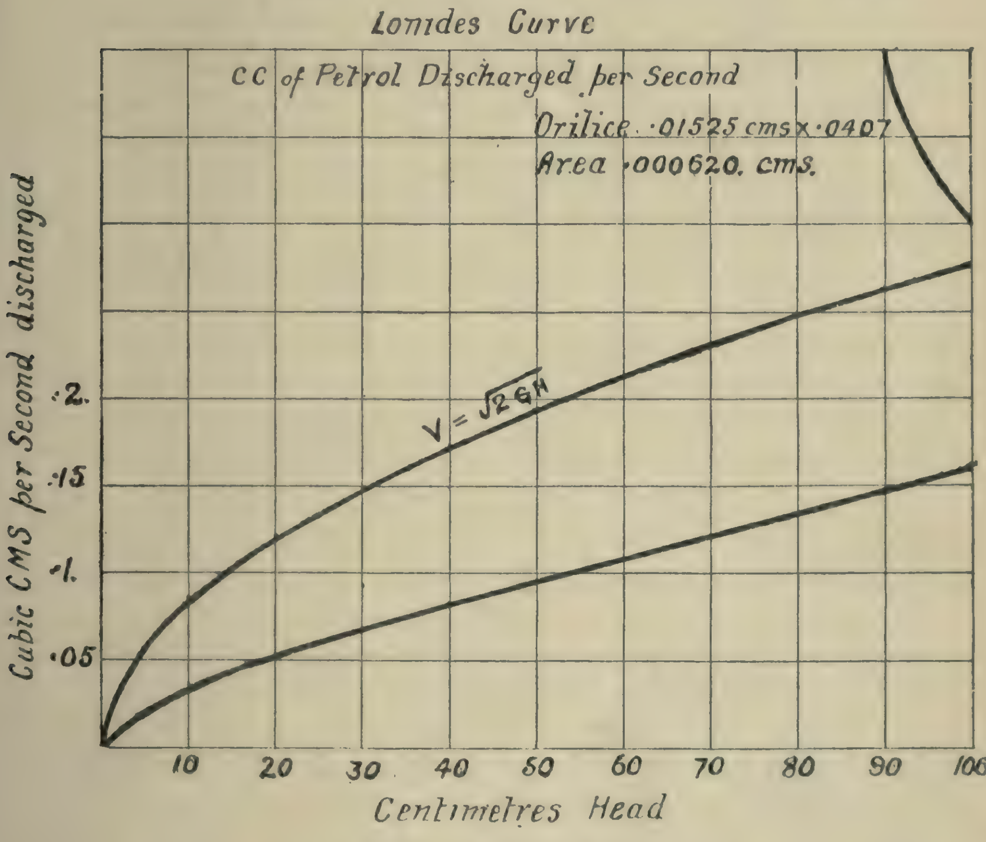

FIG. 1.—Ionides' Curve.

past the jet orifices varies more or less as the velocity of the pistons in the engine. That is to say, the curve of velocities is roughly a sine curve, rising and falling harmonically. So much for the air. Now, does the velocity of the fuel vary in the same way? It ought to if constancy of gas is to be retained. But the fuel has weight, and even at moderate engine speeds it tends to continue flowing

when once it has been set in motion. The result of this inertia is that the velocity of the fuel does not fall off as rapidly as the velocity of the air. Hence there is an excess of fuel. At higher speed this excess is naturally greater. To use an electrical term, the current of fuel 'lags' behind the current of air, just as in a circuit carrying an alternating current of electricity, and having inertia as well as resistance, the current lags behind the pressure. In the simplest case, that of true harmonic motion, the amount of lag can be defined as 'the angle between

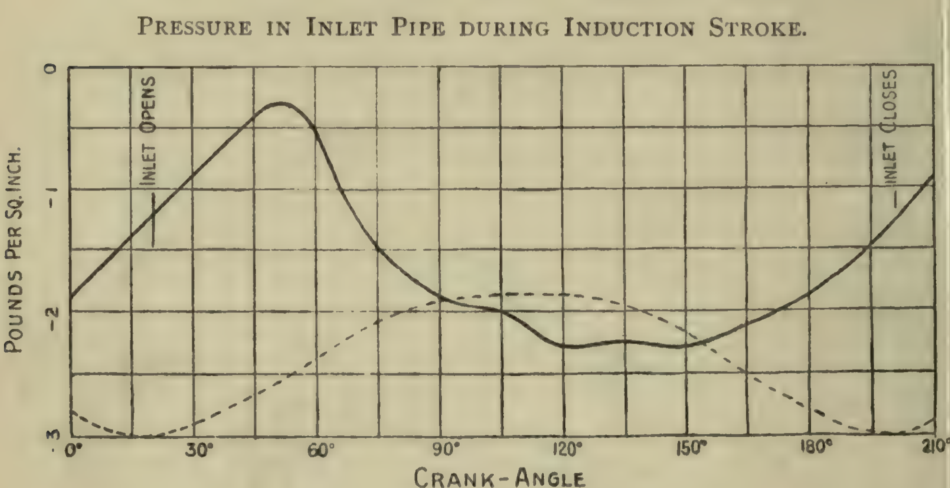

FIG. 2.—Inlet Pipe Pressure.

two points on a circle whose movement round that circle would give that lag.' In an electrical circuit, the tangent of the angle of lag is equal to 2π times the inertia (or inductance) of the circuit divided by the resistance.

"The inertia of the fuel can be calculated easily. The resistance has to be approximated, because for any practicable jet there is no true analogue to electrical resistance. The friction in a jet appears to be something between an electrical resistance, in its behaviour, and a function of the velocity of the flow.

"Still a sufficiently close approximation can be made, and a jet designed to have a resistance sufficiently high

and an inertia low enough to reduce the angular lag to a few degrees only at the highest practicable engine speed.

"Such a jet is used on the Polyrhoe. On an engine with automatic inlet valves—a condition, it is true, which favours the experiment—the absence of any material lag was fully demonstrated. The open throat of the carburettor was illuminated by a vacuum tube lighted through a contact on the half-time shaft. As this contact was rocked to light the carburettor at different phases in the cycle, the throat could be seen either full of spray or quite empty as though the carburettor were not at work."

The question of jet friction plays a large part, as may be supposed, in the question of the inertia, but this may also be accompanied by the phenomenon of capillarity, being the tendency for a liquid to creep up a small orifice in a contrary direction to that which it would normally assume under the action of gravity. Capillarity often causes a carburettor to leak by reason of the liquid either creeping up through the jet or creeping up the stem of the valve which, at its lower end, dips into a fuel reservoir, and this action has caused considerable trouble in certain types of carburettors.

Passing from the carburettor now to the inlet pipe, inertia plays a very important part in the design of inlet pipes for all types of engines, whether they be of the single-cylinder or of the multi-cylinder pattern. When we consider a four-cylinder engine firing on the usual system, namely 1, 3, 4, 2, turbulence is set up in the inlet manifold, and this turbulence is further aggravated by the inertia of the explosive mixture passing through that manifold. In such a type of pipe, particularly if the ends terminate abruptly, there is always the tendency for the fuel to load up the outer ends of the pipe by reason of the two cylinders in one pipe firing in sequence, and then the two cylinders on the other pipe. The gas flows rapidly, first towards one end of the pipe and then towards the other, and the gas-flow lags behind the cylinder demand, so that when the

inlet valve of either end cylinder is suddenly closed, the gas continues to flow down the pipe and banks up with increased richness at the two ends. Considerable difficulty has been experienced, particularly in the older patterns of engines, by reason of the end cylinders getting a different consistency of charge from that which is supplied to the middle pair of cylinders. In special designs of inlet pipes for racing cars, great care is often taken to overcome the inertia of the mixture in the pipe, and a continual flow-path is given to the gases by means of either figure-of-eight inlet pipes or circular pipes, so that the gas-flow is constant and unidirectional the whole time.

Rapid closing of the inlet valves also sets up a wave motion in the inlet pipe, and there are possibly conditions under which wave motions, thus set up, may synchronise, causing difficult conditions to occur. It is better if such waves of pressure damp each other out before reaching the carburettor, or are allowed to dissipate themselves in a chamber within the water jacket. The provision of such a chamber is referred to in connection with another phase of carburation, but it also applies here. We know for a fact that certain critical lengths of inlet pipes exist in practice, and one is often asked to explain why the lengthening or shortening of a certain pipe has led to improved results.

The explanation is that there is probably some critical wave length in the pipe in question at certain engine speeds which causes great fluctuations of pressure.

Another effect of the inertia of the incoming mixture is that at the moment of inlet valve opening, unless there is a considerable negative pressure, or pressure below that of the atmosphere in the cylinder at the time of valve opening, the explosive mixture hesitates before entry into the cylinders, and it is only when the acceleration of the piston puts a more or less sudden increase of suction upon the mixture that the mixture itself follows in behind the piston. It may occur in some engines that a negative pressure of

as much as 5 lbs. per square inch is momentarily produced somewhere about half-piston stroke, or rather later, before the inertia of the explosive mixture is overcome. After this time the mixture rapidly follows up the piston, and advantage can then be taken of the inertia by retaining the inlet valve open for some considerable time after the outer dead centre has been reached.

American practice generally retains the inlet valve open later than European practice. Some American designers retain this valve open for 40° after the outward dead centre has been reached. In European practice, however, such a late closing of the inlet valve is seldom found, and this is probably due to the fact that in Europe the valves are of larger diameter.

From the figure previously given, it will be evident that the inertia has a considerable effect upon the carburettor action by reason of pulsations being set up in the inlet pipe, due to the suction which is necessary to overcome the tendency to lag, but in a high speed engine these variations usually balance out. Whether they do or do not depends on the length and design of the inlet pipe.

A theory has been propounded that there is a considerable surging effect in the inlet pipe of the majority of engines. This surging undoubtedly occurs at low speed, as has been observed in several types of carburettors where it has been shown that at certain periods the suction decreases altogether, and the inertia of the gases in the reverse direction, after the moment of valve closing, causes the fuel to blow back out of the air orifice of the carburettor.

With the modern perfection in carburettor design, it is very often probable that as the mixture leaves the carburettor it is fairly homogeneous, but owing to the pulsations taking place in the inlet manifold, the mixture as it reaches the various engine cylinders may vary considerably in richness. At the carburettor outlet the succession of engine impulses will produce a fairly uniform flow of carburetted air, but this can scarcely be said to be

true in the manifold itself. Owing to the inertia of the gases along the pipe, there is always a tendency for the heavier particles of petrol vapour to drive towards the ends of the pipe, causing very slight and instantaneous variations of pressure in the mixture.

Certain periods in the working of an engine must occur when the pulsations of the mixture in the inlet pipe synchronise with the periodicity of the pipe itself, thus tending to upset the carburation to certain engine cylinders. Under these conditions pressure waves are set up, due to the impulses of the mixture on its way to the various cylinders, and for this reason it is necessary, in special cases where carburation is of very great importance, to keep the mixture flowing in one direction only, and not allow reversals of flow in the mixture stream to occur.

It is noteworthy that considerable improvements in carburation, particularly with six-cylinder engines, have been made by eliminating the induction pipe entirely, and coring the inlet passages within the cylinder casings. This may be accountable for by two reasons, one being that heat is added to the mixture during its rapid circuit from the carburettor to the engine; and the other being, that the passages cored through the engine itself are generally of considerable magnitude, so that the surging flow is thereby much reduced.

There is no doubt that if an inlet pipe be made of sufficient size, and that enough heat is supplied to it to prevent condensation of the vapour in the pipe, local variations of pressure will be reduced to a minimum. In one particular case of a six-cylinder engine which had been difficult to carburate with a certain type of carburettor, the re-design of this engine, with the inlet pipe eliminated and the incoming charge carried through cored passages, entirely overcame the previous carburettor difficulty.

The modern tendency to place not only the induction manifold but also the mixing chamber within the cylinder water jackets undoubtedly tends to improve carburation,

by reason of the facilities such an arrangement gives for suitably heating the fuel vapour.

It has been an axiom in the past that the area of the inlet pipe between the carburettor and the valves should not undergo any great change in dimensions, on account of the drop in velocity aggravating precipitation. In modern practice, however, when a drop in velocity is permitted, and hot walls are presented, any liquefaction of vapour or precipitation of suspended particles is suitably met by hot surfaces.

When the percentage of heavier fractions in the fuel is high, any temperature obtained in the water jackets is insufficient to evaporate such fractions when precipitated, as such temperature is below 100° C. High velocity must, therefore, be resorted to, in order to maintain such particles of fuel in suspension.

Furthermore, a manifold of considerable capacity tends to damp out all those pressure variations previously referred to, and equalise out the suction at the carburettor jet.

Reverting again to the question of inertia, and the difference between that of the fuel and that of the air in a carburettor system, we must not confuse the vapour with the liquid fuel. If all the fuel is vaporised in the carburettor and properly mixed with the air, although the vapour density is about three times that of the air, the maximum variation in the volume of fuel vapour is only between 1.2 and 3.2 per cent. (Dr Watson) of the volume of the air. However, if the fuel is only partly vaporised, fuel is carried in suspension, and it is from these suspended liquid particles that difficulties occur.

Dr Watson, in his experiments upon a four-cylinder four-cycle motor, made some interesting indicator measurements of the pressures in the induction pipe at different speeds of engine rotation. He showed that at a speed of 656 revs. per min. the pressure at the moment of inlet valve opening, *i.e.*, 20° late, was slightly above atmospheric,

and continued to rise even after the valve had opened, due to the inertia of the mixture in the pipe. As soon as the valve opened appreciably, *i.e.*, at a crank angle of 45°, the pressure fell to atmospheric, and rapidly dropped to a minimum of – 1.3 lbs. per square inch, where it continued until at 150° crank angle it was at – 1 lb. per square inch. At the moment of valve closing, *i.e.*, at a crank angle of 200°, or 20° late, the pressure had risen to slightly above atmospheric.

When the engine speed increased to 860 revs. per min. the pressure at valve opening was down to – 0.4 lb. per square inch, with a maximum depression of – 1.8 lbs. per square inch, and rising to – 0.3 lb. per square inch at valve closing.

At a speed of 1,200 revs. per min. the corresponding pressures were – 1.2 lbs. per square inch at valve opening; maximum depression, – 2.3 lbs. per square inch; and – 1.2 lbs. per square inch at valve closing.

From the following table it will be seen that the pressure in the induction pipe at the moment of valve closing is above the mean pressure :—

TABLE XVIII.

Speed Revolutions per Minute.	Mean Pressure, Lbs. per Square Inch Gauge.	Pressure (Gauge) at Moment of Valve Closure, Lbs. per Square Inch.
656	– 0.9	+ 0.1
860	– 1.2	– 0.4
1,200	– 1.7	– 1.2

This engine can scarcely be taken as an example of modern design, on account of the apparent smallness of its valves which have caused the wire drawing.

The area through the carburettor was also probably a good deal less than would be the custom in modern practice, where a sufficient area is provided to permit

engines to attain speeds of 2,500 revs. per min. in normal working.

In Dr Watson's engine the volumetric efficiency varied from 78 per cent. at 500 revs. per min. to 63 per cent. at 1,300 revs. per min., which can scarcely be considered good. These values could easily be brought up to 90 per cent. at the lower speed, and 80 per cent. at the higher, by suitable design.

A useful formula for measuring the weight of air passing through a circular opening is as follows :—

$$W = \alpha F t \sqrt{2p\rho}.$$

Where W = the weight of air in lbs. or grm.

F = the area of the hole in sq. ft. or sq. cm.

ρ = the density of the air in lbs. per cub. ft. or cub. cm.

α = the coefficient of contraction of the orifice = about 0.597.

t = the time in seconds.

p = the pressure difference in lbs. per sq. ft.

CHAPTER V

THE FLOW OF FUEL THROUGH SMALL ORIFICES

THE subject of the following few chapters has been one to which the author has given particular attention, and in the absence of authoritative matter from an engineering point of view, dealing with very small orifices, no system of units has become standardised for this purpose.

Some explanation, therefore, is due with regard to the units adopted, and the reasons why the author has presented the matter in this form.

The linear dimensions of the apparatus are most conveniently expressed in millimetres, as this unit of length is particularly suitable for small work. The unit of volume would be preferably expressed in litres or cubic centimetres, and scientifically this unit should be adopted for the liquid. Swept volume of an engine is taken wherever possible in cubic centimetres, as this volume is obtained directly from linear measurement and calculation. Where relations exist between swept volume and fuel consumption for the purpose of calculation, the cubic centimetre is adopted as the unit.

This book, however, is not solely written for the purpose of scientific investigation, but is also for the practical application by the motorist. Fuel is sold at present in England by the Imperial gallon, and abroad by the American gallon, or the litre, and for this reason, where ready practical application of the data is possible, the Imperial gallon is taken as the volumetric unit for fuel.

The unit of pressure is a somewhat difficult one in a carburettor system, on account of its small magnitude, and the author has adopted that unit which is usually employed in connection with fan work, namely, the inch of water head. This is more convenient than the inch of mercury,

as a water manometer is simple to construct, and the medium under observation can be readily obtained.

Fractions of a pound per square inch or grammes per square centimetre might lead to some complication, and it must be distinctly understood that where the term "inches of water head" is used it is merely an indication of difference of pressure, and has nothing whatever to do with water or petrol or any other fuel, and it does not, therefore, apply in the hydraulic sense as representing the head of the fuel over the orifice.

In discussing the control of fuel through an orifice by means of some tapered pin device, it has been suggested to the author by Mr A. S. E. Ackermann, A.M.I.C.E., that the use of the word "modulating," as applied to the pin, really expresses the function of this pin better than any other word in common use, and a module is a thoroughly well-known appliance, having existed for many centuries.

The ruling factors in the determination of the quantity of liquid fuel which will flow through a carburettor jet orifice are:—

(*a*) The viscosity of the fuel.
(*b*) The temperature of the fuel.
(*c*) The shape of the orifice.
(*d*) The effective head actuating at the orifice.

With reference to the first two, these bear a certain relation to one another, as the higher the temperature the lower will be the viscosity of the fuel, and the greater volume will flow through a small orifice in unit time as the temperature is increased.

If, therefore, in motor car practice radiation or conduction of heat from the engine is allowed to influence the float chamber and the liquid contained therein, an increase of fuel supply will result as the engine warms up.

If regulation is perfect before the engine has reached working conditions of temperature, the mixture will be too rich in running, and, conversely, difficulties may be ex-

perienced until working temperature is arrived at with an instrument which is non-adjustable.

Broadly speaking, therefore, where efficiency is to be maintained at all times, a fuel adjustment which will be proportionately progressive from minimum to maximum opening of the fuel and air orifices is essential.

Dealing, in the first instance, with the important question of the viscosity of fuels at different temperatures, the author some years ago conducted a series of experiments to ascertain the effect of a rise of temperature of the fuel in the Claudel carburettor. It will be remembered that this instrument is provided with a water-jacketed base, so that the fuel itself is heated on its way to the jet orifice.

For the purpose of these tests the author used a glass instrument of the double sphere type having a constricted opening between the upper and lower sphere. The whole instrument was immersed in a water bath, and the temperature noted. The following table gives the time in seconds for the measured quantity of fuel to pass through the constriction. Two fuels only are given, the ordinary commercial motor spirit and a heavier distillate, between 150° C. and 300° C.

TABLE XIX.*—FUEL: "ANGLO 0.760" SPIRIT.

Effects of temperature upon viscosity. Head over orifice = 60 *mm.*
Tests of sample quantity through instrument.

	Fuel: "Anglo 0.760" Spirit.	Petroleum Distillate between 150° and 300° C.
Temperature ° F.	Time taken in seconds.	Time taken in seconds.
58	270	400
75	255	390
90	220	375
110	180	...
120	165	...
135	150	...

* This is a duplicate of Table XIII., and is here inserted for the convenience of the reader.

At the same time the specific gravity of the fuel was taken at different temperatures, and the values are given in the following table :—

TABLE XX.*—TEMPERATURES AND SPECIFIC GRAVITIES.

Fuel Tested: "*Anglo* 0.760."

Temperature in ° F.	Specific Gravity.	Temperature in ° F.	Specific Gravity.
54	0.732	81	0.720
60	0.730	86	0.718
65	0.728	90	0.715
70	0.725	95	0.713
75	0.723		
Theoretical.			
100	0.710	120	0.700
110	0.705	130	0.695

The above table indicates that there was a reduction of approximately 0.005 in the specific gravity per 10° F. rise in temperature.

Now we will proceed to deduce from the above two tables what is the net effect of heating the fuel. For example, we find that at 60° F. the specific gravity is 0.730, and at 90° F. it is 0.715, and at approximately the same temperature, 58° F., the time for unit volume to flow is 270 secs., and at 90° F. the time is 220 secs.

We may say that in one second the relative number of heat units passing through the orifice is proportional to the specific gravities of the fuels at those temperatures. We therefore have, taking the specific gravity of water at 1,000 :—

$$\text{At } 60^\circ \text{ F. } \frac{730}{270} = 2.7,$$

$$\text{at } 90^\circ \text{ F. } \frac{715}{220} = 3.24,$$

$$\text{and the ratio } \frac{3.24}{2.7} = 1.2\ ;$$

* This is a duplicate of Table XVI., and is here inserted for the convenience of the reader.

which means there is an increase of 20 per cent. in flow of fuel as far as thermal units per unit time are concerned when the temperature is raised from 60° to 90° F.

Let us compare these figures with those obtained by Sorel, who experimented with a tube 49 cm. in length, with a fuel head of 30 mm., the average diameter of the tube being 0.775 mm. These experiments were more extensive and exact than those of the author, so that the values can be depended upon under the conditions prevailing, but it must be borne in mind that a long tube and a fuel nozzle are different in their behaviour.

Referring to Sorel's data, fuel No. 6, a petroleum distillate of sp. gr. 0.700, boiling between 12° C. and 134° C., and taking the time of flow as constant, measuring the weight of fuel flowing through the tube at different temperatures, the specific gravity is therefore eliminated. We see that at 15° C., say 60° F., and at 32.5° C., say 90° F., the following weight of grammes passed through the tube :—

$$\left.\begin{array}{r} 15^\circ \text{ C.} = 72.5 \text{ grm.} \\ 32.5^\circ \text{ C.} = 78.5 \text{ grm.} \end{array}\right\} \frac{78.5}{72.5} = 1.08.$$

That is, when the fuel was heated and passed through a *long* tube of small diameter its increase of flow was 8 per cent. when the fuel was of low density.

As the density of the fuel is increased, the rate of discharge at a higher temperature rapidly increases, as compared with the rate of discharge when the temperature is low. Between the same limit of temperature Sorel's results show that with a fuel of 0.755 sp. gr. the increase in the flow of fuel is 18 per cent., which agrees very well with the figures obtained by the author.

The following table is taken from Sorel's book, p. 163, and is of some importance at the present time, dealing as it does with different fuels :—

TABLE XXI.—THE WEIGHT OF VARIOUS LIQUIDS FLOWING THROUGH A CAPILLARY TUBE IN ONE HUNDRED MINUTES UNDER A HEAD OF 30 MILLIMETRES OF THE SAME LIQUID (SOREL).

Substance.		Temperatures Centigrade. 5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°
		Grm.	Grm.	Grm.	Grm.	Grm.	Grm.	Grm.	Grm.	Grm.	Grm.	Grm.	Grm.
1. Water - - -		...	42	80	91	101.5	115	129.5	140	153.7	167	181	195.5
2. Pure 90 per cent. alcohol		...	14.6	17.7	90.2	21.5	25	28	33	39.5	46	52.5	60
3. French denatured alcohol		17.5	19.7	22.3	25.3	28.3	30.2	33.3	36.5	40.5	45.3	50.0	54.5
4. Pure benzene - -		49.3	56	62.3	68.6	75.6	82	87.6	92.5	97	102.5	108	113.5
Substances Extracted from American Petroleum.													
Sp. Gr.	Boiling at												
6. 0.700	12° to 134°	68	70.5	72.5	74	75.7	77	80	84	89.7	96.5	...	...
7. 0.725	70° „ 134°	48.3	52.5	56	59.8	63.3	66.3	69.7	73	76.7	80.2	...	...
8. 0.755	125° „ 196°	39.8	41.5	42.5	44.7	47.8	51.5	54.5	58	61.7	65.7	70.3	76.5
9. 0.788	196° „ 250°	16.5	19.6	21.5	25.2	28	31	34	36.5	39.5	42.2	45	48
10. 0.817	250° „ 310°	7.5	8.6	10.2	11.7	13	14.3	15.9	17.5	19.2	21	23	25

As a supplement to this table a few figures obtained by the author, using Claudel jets, with a constriction 5 mm. long in every case, may be of interest.

TABLE XXII.—TIMES TAKEN FOR 60 C.C. OF LIQUID FUEL AT 55° F. TO FLOW THROUGH AN ORIFICE 0.95 MM. DIAMETER.

Fuel.	Specific Gravity.	Head over Orifice in mm.		
		30	40	60
		sec.	sec.	sec.
"Anglo 0.760" - -	0.730	77	70	50
Distillate from paraffin	0.795	165	142	...
Benzol - - -	0.885	105	97	76

The Jet.—A carburettor jet has two functions to perform—first, that of spraying the fuel into the mixing chamber, and second, that of regulating the amount of fuel passing through the carburettor in unit time. We have already dealt with the question of spraying, and we now proceed to discuss how different types and forms of jets can be designed and arranged to carry out the measuring operations. It is a matter of history that a jet was not at first employed, as the surface carburettor was not provided with a jet. With the advent of the Maybach instrument the jet came into use, and is now almost universally adopted.

The modern carburettor designer does not by any means hold to one particular type of jet, such as the circular orifice or drilled hole which was the pioneer. We now have the annulus and the slit, which may be variable in opening ; also combinations of the two. Special forms of jet are now very much in vogue, whose object is to control the flow of fuel without the assistance of extra air devices.

We will briefly consider the conditions under which a fuel jet has to work in ordinary practice, and it is quite conceivable that, owing to the road resistance being high,

an engine may rotate at a slow speed with the throttle wide open. Subsequently the engine speed may increase, and the throttle closed down when the resistance diminishes. During both these periods the power developed by the engine may be the same, but, owing to some peculiarity of carburettor design, the depression in the vicinity of the jet may vary under these two conditions of working.

At the higher engine demands we may also find the

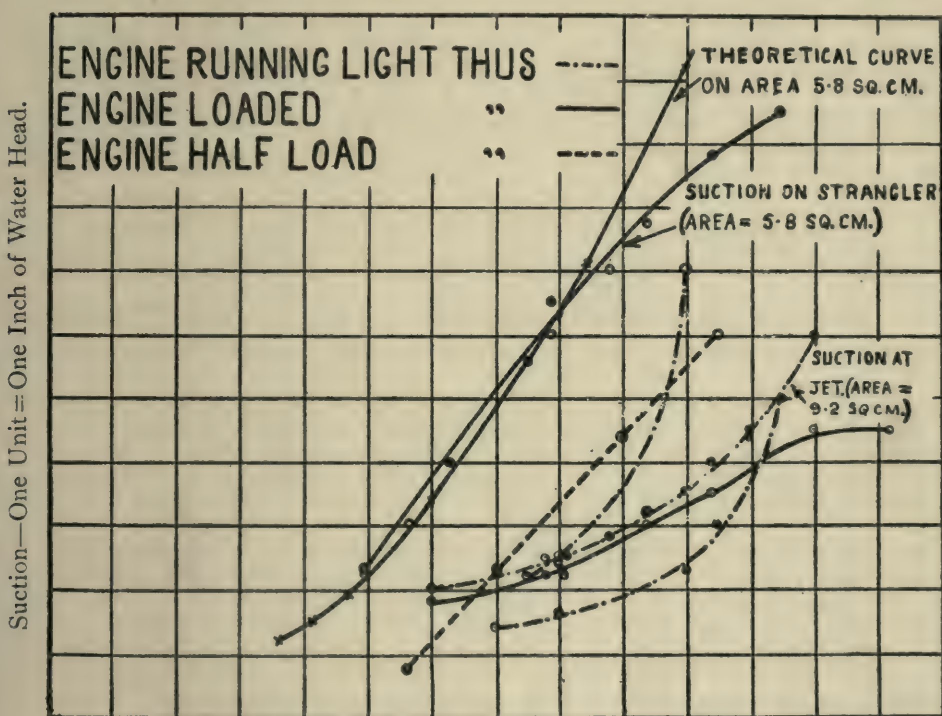

FIG. 3.—Revs. per Min. of Engine—One Unit = 100 Revs. per Min.

carburettor opened out to its maximum capacity and the engine speed gradually increasing. The suction acting upon the jet also increases, and causes a greater efflux of fuel, and it is the duty of the jet to so proportion the fuel-flow to air-flow that the mixture shall remain of constant composition at all times.

We may have an instance where the throttle is close to the jet, and closes the air-flow around it when the engine demand is small—the suction is thus increased at the jet

orifice. But in the first example we find the same small demand with wide-open throttle and low engine suction. The driver of a modern car does not consider these conditions, hoping that by opening up his throttle the engine power will respond at all times.

It is unnecessary to point out that at low air velocities a jet device behaves erratically, as this has already been shown graphically and otherwise by the author and others from time to time. In order to get over these difficulties there are two alternatives, one being the system already described of concentrating the air-flow round the jet at low engine speeds, and the other being to provide a separate jet for slow running.

The Passage of Petrol through a Single Orifice.—The object of the experiments contained in this series was to obtain some practical data for the use of the motoring world at large, as distinct from purely theoretical deductions.

The test apparatus consisted of a small brass tank, having a tube fixed into the bottom, which terminated at the other end in a tee-piece. Into this tee-piece jet tubes were screwed in turn, each orifice having been carefully drilled to an accuracy limit of the stated diameters, the maximum error being $\frac{1}{100}$ mm. The orifices used in the experiments ranged from 0.95 mm. to 1.40 mm. diameter. The head of the liquid was varied within wide limits.

For the first series, pressure heads between 30 mm. and 90 mm. were taken in order to ascertain the probable friction in the tube at low speeds of the fuel, but with the 30 mm. heads less liquid passed through than would be the case in actual practice, except under conditions of no load or very light load. The 90 mm. head corresponds to the suction when the car is running on a level with the throttle very slightly open.

In carrying out these experiments the fuel in the tank was kept at a constant level, and the time noted in which a given quantity of fuel passed through the orifice in the

jet tube. This was done for heads of 30, 60, and 90 mm. and upwards with each size of jet, and the appended Table XXIII. shows the quantity of fuel which passed through the orifice in gallons per hour, and the time taken in seconds for the sample quantity. Intermediate values have been filled in from the curves produced experimentally, and the values have been cross checked, *assuming* that the flow has been proportional to the area of the jet (or to d^2) and to the square root of the head $= h$.

TABLE XXIII.—CLAUDEL HOBSON CARBURETTOR. JETS OPEN-ENDED.

Diameter of Orifice in mm.	Head of Fuel in mm.	Quantity Flowing in Gallons per Hour $= Q = \frac{45}{t}$.	Time taken for Unit Quantity to Flow $= t = \frac{3600}{80 \times Q}$.	Diameter of Orifice in mm.	Head of Fuel in mm.	Quantity Flowing in Gallons per Hour $= Q = \frac{45}{t}$.	Time taken for Unit Quantity to Flow $= t = \frac{3600}{80 \times Q}$.
			secs.				secs.
0.95	30	0.32	140	1.20	30	0.515	87
,,	60	0.454	99	,,	60	0.725	62
,,	90	0.562	80	,,	90	0.895	50
,,	120	0.645	69	,,	120	1.03	43
,,	150	0.725	62	,,	150	1.16	38
1.00	30	0.352	127	1.25	30	0.56	80
,,	60	0.51	88	,,	60	0.786	57
,,	90	0.62	72	,,	90	0.97	46
,,	120	0.715	62	,,	120	1.116	40
,,	150	0.805	55	,,	150	1.25	35
1.05	30	0.392	114	1.30	30	0.608	73
,,	60	0.554	81	,,	60	0.85	52
,,	90	0.684	65	,,	90	1.052	42
,,	120	0.786	57	,,	120	1.208	37
,,	150	0.886	50	,,	150	1.36	33
1.10	30	0.433	104	1.35	30	0.655	68
,,	60	0.61	73	,,	60	0.915	49
,,	90	0.752	59	,,	90	1.13	39
,,	120	0.865	52	,,	120	1.30	34
,,	150	0.974	46	,,	150	1.465	30
1.15	30	0.474	95	1.40	30	0.705	63
,,	60	0.665	67	,,	60	0.987	45
,,	90	0.821	54	,,	90	1.216	37
,,	120	0.943	47	,,	120	1.4	32
,,	150	1.064	42	,,	150	1.58	28

Certain experimental errors have crept in, particularly at the lower values, owing to the orifice at times becoming partially fouled, but in the table these errors are neglected, and approximately true values given by calculation, assuming the square root law to hold good. On the whole, however, the experimental points have agreed very well, and the curves have been plotted so as to average the results obtained.

In conducting these tests it was remarkable how easily

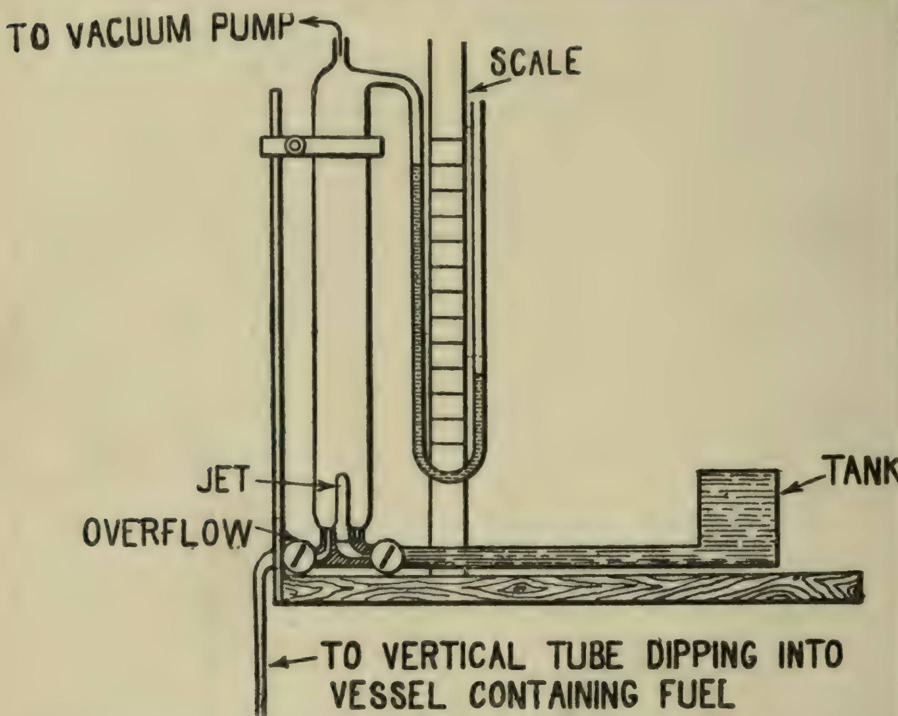

FIG. 4.—Brewer's Apparatus for Testing Fuel Flow through Jet Orifices.

the flow through the smaller orifices became erratic, which may account for the difficulty that is often experienced in practice in running an engine very slowly for any length of time.

The figures shown in the foregoing table were not conclusive, so the author conducted numerous other experiments with an instrument which he designed for the purpose. This consisted of a long vertical tube, into the base of which the desired jet could be screwed,

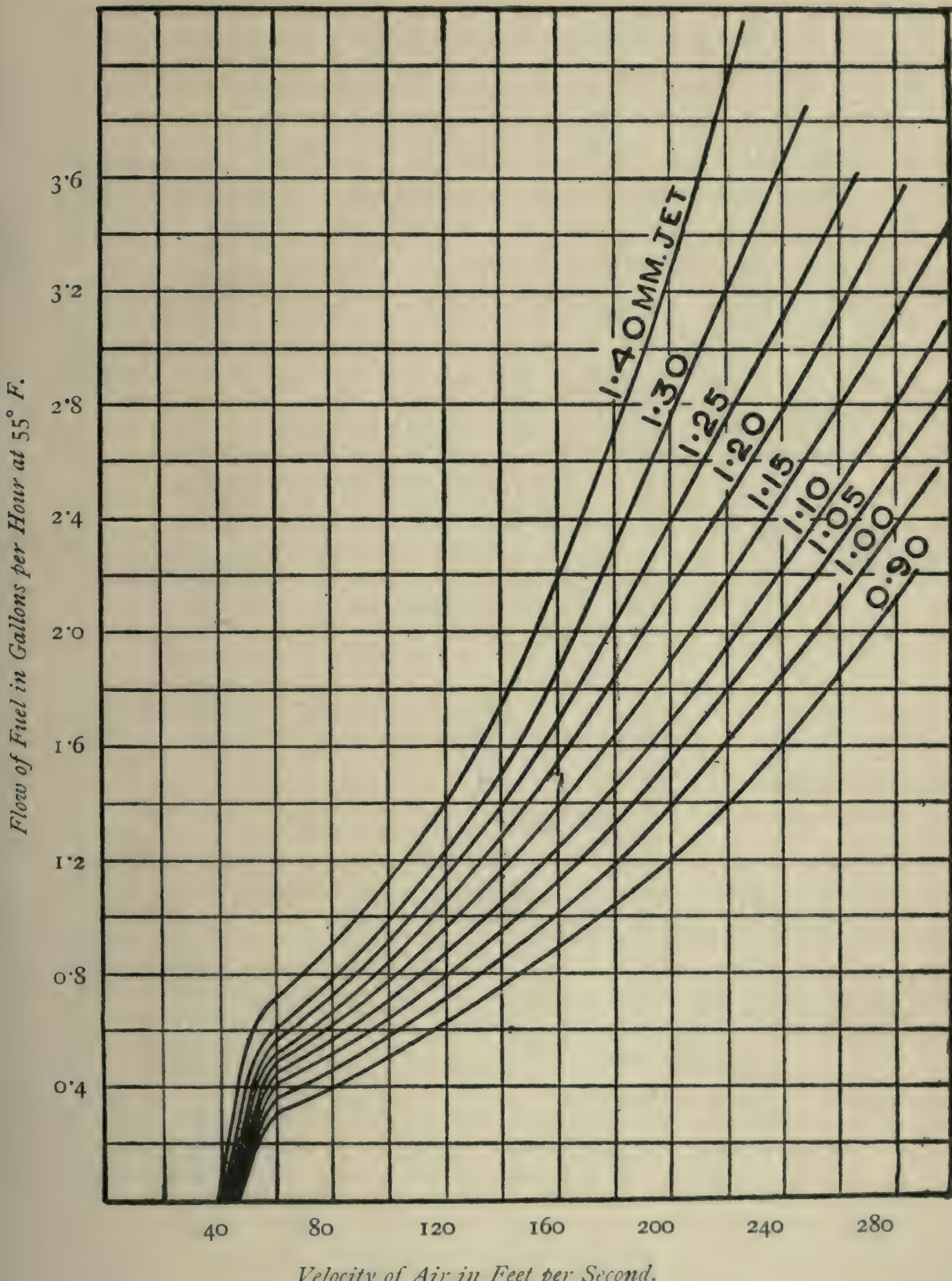

FIG. 5.—Observed Flow of Fuel through Circular Orifices.

a manometer gauge being fitted, so that the depression within the tube could be ascertained. Leading to the tube was a fuel supply pipe, fitted with a small tank and constant level device, the discharged fuel being led away by a drain at the base of the tube. A vacuum pump was attached to the top of the vacuum tube, so that any desired vacuum could be produced in the tube, a manometer indicating the vacuum or depression at the jet orifice.

Fig. 5 shows graphically the results of the experiments, the air velocity in feet per second, corresponding to the various suctions, being the abscissæ, and the ordinates being the gallons of fuel discharged per hour.

Studying these curves, we notice that at the lower end, towards the origin, there is a lag in the flow due to the surface tension of the liquid fuel. The fuel does not emerge from the jet until the depression amounts to $1\frac{1}{2}$ in. to 1 in. head of fuel. As the air velocity increases by regular intervals, we find that the fuel discharge values lie upon curves having a well-formed characteristic. The shape of this characteristic depends upon the shape of the fuel orifices and conditions of testing, and one cannot say that a certain experimenter is wrong and another right because the curves produced by different methods of testing and with different apparatus do not agree. The point is, however, that the fuel discharge curves, obtained by plotting air velocity and discharge in unit time, are not straight lines, but certain portions of these curves are practically straight, and can thus be utilised for working limits in any particular design of instrument.

The Circular Jet.—The most usual type of jet orifice met with in practice is circular. It is difficult to drill accurately a true hole of small dimensions, and in experimental work errors in workmanship have caused much trouble, as supposedly similar jets have varied widely in their performance.

A circular orifice is the fundamental feature of the Zenith carburettor, and in designing the same, use is made of Rummel's formula for rate of petrol discharge from a jet :—

$$c_1\left(\frac{Q}{t}\right)^2 + c_2\left(\frac{Q}{t}\right) = h,$$

where c_1 and c_2 are constants, being the coefficient of discharge for the orifice.

The formula used in the experiments made by the author to ascertain the value of c for petrol jets of the dimensions ordinarily in use, was

$$Q = c\omega\sqrt{2gh},$$

where Q is the discharge in cubic centimetres per second,
c is the coefficient of discharge.
ω is the area of the orifice in square centimetres.
g is the acceleration due to gravity in centimetres per second per sec. = 981
h is the head in centimetres over the orifice.

In the case of water it has been found that for pressure heads up to 4 in. the value of the coefficient of discharge varied from 0.738 to 0.770, the mean coefficient being approximately 0.75, which agrees well with the value 0.77 given by Professor Unwin on p. 88 of his "Treatise on Hydraulics."

This coefficient of discharge, however, applies only to a portion of the curve plotted with fuel discharge as ordinates, and air velocity as abscissæ.

Using Claudel jets, with the end screw removed so as to eliminate the balancing effect of the tube, the author found that at low heads the friction of the jet orifice is very noticeable, and that as the diameter of the orifice increases the coefficient of discharge appears to increase also. He also found that, using water as the medium, the surface tension of the water in a jet of 1.10 mm. diameter is only overcome by a head of 10 to 15 mm., equal to an air velocity past the jet of 40 to 50 ft. per second.

If we examine the curves (Fig. 6) of discharge of petroleum spirit from circular orifices, which are drawn from the author's original charts, with the difference that the abscissæ are the square roots of the water head in inches, the following characteristics will be evident.

First, we note that the origin of the curves is, when

Fuel Flow from Circular Orifices. Length of each Orifice, 5 *times its Diameter. Fuel at* 55° *F.*

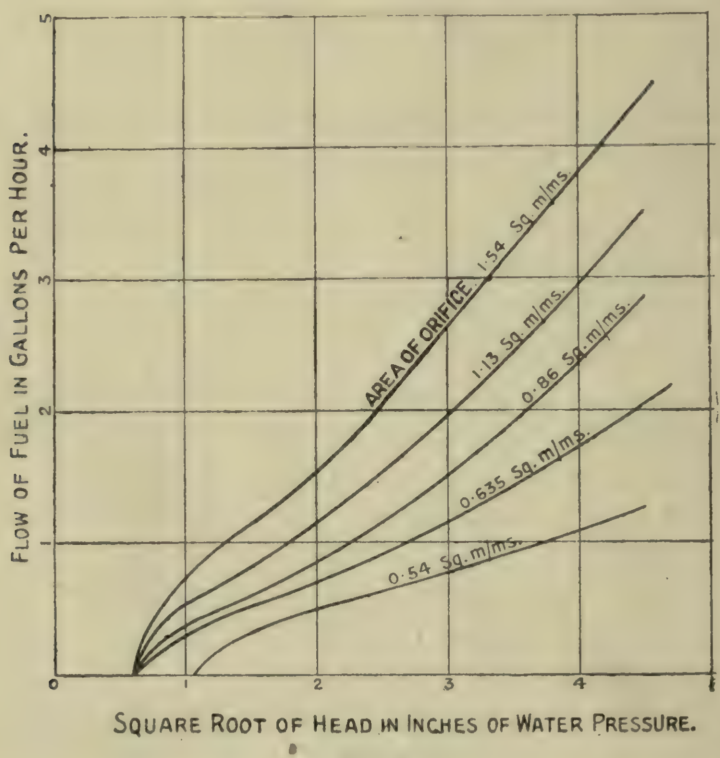

Fig. 6.

approximated by a straight line through each, located at 0.5 from the true origin. This corresponds with the Brewer orifice, so we may, in fixing an equation for these curves, base it upon $(\sqrt{h}-0.5)$ as in the Brewer orifice, as the origin on the axis of x. We then notice the method in which the curve rises above the straight line drawn through the false origin, to dip again in the centre and

rise at the maximum observed head. Supposing the straight line of true flow be drawn through the true origin, the deviation of the observed flow is still more marked at the upper ends of the curves.

The small orifice tested by Rummel does not show so great a deviation, no doubt due to its small dimensions. The author found that the error increases with the size of the orifice, probably showing that the proportionate jet friction is greater with the smaller orifices even at higher rates of flow.

Only an approximation can be made to an equation for these curves, in terms of $y = m(x - c)$, where m is the tangent of the angle, and it will be seen that approximately the flow of fuel in terms of the area of the orifice and the square root of the head is as follows :—

Q = flow in gallons per hour.
h = head in inches of water pressure.

TABLE XXIV.—EQUATIONS FOR FLOW CURVES, CIRCULAR ORIFICES.

Diameter of Orifice, mm.	Area, sq. mm. $= A$.	Values of Q = the Flow in Gallons per Hour of Petrol in Terms of $(\sqrt{h} - 0.5) \times m$.	
		Q.	Q.
1.40	1.54	$(\sqrt{h} - 0.5)$	$\frac{A}{1.54}$
1.20	1.13	$0.8\ (\sqrt{h} - 0.5)$	$\frac{A}{1.4}$
1.05	0.86	$0.66\ (\sqrt{h} - 0.5)$	$\frac{A}{1.3}$
0.90	0.635	$0.45\ (\sqrt{h} - 0.5)$	$\frac{A}{1.4}$
0.85	0.54	$0.33\ (\sqrt{h} - 0.5)$	$\frac{A}{1.63}$

The last column gives the flow of fuel approximately in gallons per hour per square millimetre of orifice area, taking into consideration the pressure acting in accordance with Unwin's formula on p. 6.

For example, $Q=0.33(\sqrt{h}-0.5)$ for an orifice 0.85 mm. diameter, but this is only approximate throughout the whole working range.

To bring these orifices into line with others under consideration we will endeavour to find the constant K, relating one sized orifice to another, and for this purpose the following table is taken from the foregoing curves for orifices of various sizes giving the same flow of fuel under different heads :—

TABLE XXV.—FLOW, 1 GALL. PER HOUR, CIRCULAR ORIFICE, WITH SPIRIT.

$\sqrt{h}$.	Area.	$nA \times (\sqrt{h}-0.5)$.	K.
Inches.	Sq. Mm.		
3.7	0.54	0.57	1.75
2.7	0.635	0.63	1.59
2.3	0.86	1.02	0.98
1.8	1.13	1.17	0.855
1.3	1.54	1.23	0.815

That is to say, that $KnA(\sqrt{h}-0.5)=1$ gall. per hour, *i.e.*, $1.75 \times 0.57 = 1$, and from the above it will be seen how much the value of K varies with the area of the orifice.

In the above table n is a factor relating the areas and the square root of the head for their different values.

These figures should be compared with those given for the Brewer orifice on p. 96.

Take for example a flow of petroleum spirit of 2 galls. per hour through a circular orifice.

TABLE XXVI.—FLOW, 2 GALLS. PER HOUR.

Diameter of Jet, mm.	Area, sq. mm.	Head in inches of Water.	$\sqrt{h}$ inches.	$(A\sqrt{h}-0.5)$.	K.
1.40	1.54	6.3	2.46	3.02	0.663
1.30	1.33	7.0	2.55	2.73	0.732
1.20	1.07	9.5	3.09	2.77	0.722
1.15	1.02	10.0	3.16	2.72	0.735
1.05	0.86	13.0	3.61	2.68	0.746
1.00	0.785	14.3	3.78	2.58	0.775
0.90	0.635	16.7	4.10	2.29	0.875
For water these figures become					
1.20	1.07	12.0	3.47	3.18	0.63
1.15	1.02	18.5	4.31	3.89	0.514
1.00	0.95	19.5	4.42	3.73	0.535

In the above calculation an attempt has been made to show the relation existing between the flow of fuel through the orifice, the area of the orifice, and the square root of the pressure head, and a multiple K is introduced representing a factor relating the variables, as follows:—

We find that a flow of 2 galls. per hour is produced by any of the combinations in the above table, and if the discharge curves were straight lines having an origin along the line of abscissæ at a distance equal to $\sqrt{h}=0.5$, the value $A(\sqrt{h}-0.5)$ multiplied by the tangent of the angle between the curve and the base line, would indicate the curve of fuel discharge. A figure represented by K is here introduced, and referring to the curve (Fig. 6) and the table above, we will take, for example, the orifice 1.13 sq. mm. area and locate the curve of fuel discharge.

When $\sqrt{h}=4.0$, $y=2.9$, and $4.0-0.5=3.5$, therefore the tangent of the angle of the curve whose origin is on the axis of x at position $0.5=\frac{2.9}{3.5}=0.83$, and the flow in gallons per hour at any suction = the square root of the suction in

inches of water head minus 0.5 in inches of water head × 0.83, approximately, as the curve is not a straight line.

This value does not take into account the area of the orifice, and for this reason the value of K is adopted, which includes the tangent of the angle and the area of the orifice.

It will be interesting to note how the foregoing figures compare with the results of Professor Morgan's experiments, which were carried out on somewhat similar lines, though the areas and characters of the orifices were not made known.

The author has endeavoured to calculate as nearly as possible the air velocities and depressions from such data as are available, and has taken the velocity of air through the choke tubes from the known volume of air passing, divided by the area of the choke tube. This is not, of course, accurate, as no account is taken for the coefficient of the choke tube; but in the absence of data as to its shape, it has been thought better to ignore this factor. When examining the tables, therefore, only relative and not actual values must be considered.

The figures have been worked out and arranged so as to be comparable with others in this book. The coefficient of discharge of the orifice should be particularly noticed.

TABLE XXVII.—COMPUTED FROM FIG. 8 IN PROF. MORGAN'S PAPER.

Choke, $\frac{3}{4}$ in. diameter. Area = 0.44 sq. in.

Cub. ft. per min.	Velocity of Air Flow, V ft. per sec.	Equivalent h in inches of Water.	$\sqrt{h}$.	Q. Cub. cm. per min.	Q. Galls. per hr.	$\frac{Q}{\sqrt{h}-0.4}=C.$
19.5	107	2.8	1.67	50	0.66	0.52
27	148	6.0	2.45	75	0.99	0.48
34	187	8.5	2.92	100	1.32	0.525
41	224	11.5	3.4	125	1.65	0.55
49	268	14.5	3.8	150	1.98	0.582
56	306	17.5	4.2	175	2.31	0.608

Air curve, false zero, at 27 ft. per sec. velocity = 0.17 in. of water.

TABLE XXVII. (*continued*).

Choke tube, 1 in. diameter = 0.785 sq. in. area.

Cub. ft. per min.	V ft. per sec.	Equivalent h in inches of Water.	$\sqrt{h}$.	Q.		$\frac{Q}{\sqrt{h}-0.4}=C.$
				Cub. cm. per min.	Galls. per hr.	
22	67	1.1	1.05	25	0.33	0.508
36	110	2.8	1.67	50	0.66	0.520
50	153	6.1	2.48	75	0.99	0.475
60	183	8.5	2.92	100	1.32	0.525

Air curve, false zero, at 24 ft. per sec. velocity = 0.16 in. of water.

We will now examine in the same manner Professor Morgan's curve, as shown in Fig. 13 of his paper before the Institution of Automobile Engineers (*Proc.*, vol. v. p. 50), in which the flow of fuel is plotted with the square root of the head. In this example the effective heads are much smaller than are usually met with in practice. The author has prepared the following figures as accurately as possible from the printed graph. The author, however, thinks that the line connecting the observed points is incorrectly drawn, as it should not go directly to the origin, but the figures are taken from the curve showing no false zero.

TABLE XXVIII.—COMPUTED FROM PROF. MORGAN'S EXPERIMENTS.

$\sqrt{h}$		Q.		$\frac{Q}{\sqrt{h}}=C.$
Mm. of Water.	Inches of Water.	Cub. cm. per min.	Galls. per hour.	
6	0.23	25	0.33	1.43
8	0.315	50	0.66	2.09
13	0.512	75	0.99	1.93
17.5	0.69	100	1.32	1.91
22.5	0.89	125	1.65	1.85
27	1.06	150	1.98	1.87
32	1.26	175	2.31	1.83
37	1.40	200	2.64	1.88

If one studies the action of carburettors of the Vapour or Zenith type, the shape of the characteristic curve of petrol discharge through a small orifice must be borne in mind, and the position of the normal working of the main jet must be located upon this curve. In the ordinary single-jet carburettor it is the custom to allow such relative dimensions of jet, air passage, and other ruling factors that the single jet is of sufficient size to pass the necessary quantity of petrol at low speeds. At high speeds, therefore, either air must be added or the normal suction decreased, so that, as the upper portion of the discharge curve is worked upon, there is no excess of fuel discharge. In the Zenith and Vapour carburettors the size of the normal jet is arranged so that its working range is on the upper portion of the discharge curve, which is practically a straight line. Such a jet is too small to give a sufficient discharge at low suction values, and a supplementary supply of fuel must be admitted in order to produce an explosive mixture. This supply is regulated by a separate jet, giving a more or less constant discharge, and in the Vapour carburettor the size of the small air admission hole above the petrol well regulates the amount of fuel which can flow through the by-pass hole, and, incidentally, has a marked effect upon the compensating flow at low speeds.

Varying speeds at varying loads are demanded with different fuels under different conditions of atmosphere and temperature, and these conditions cannot all be met successfully by any ordinary single-jet carburettor, by reason of the principle upon which it works. The addition of spring-controlled extra air devices to meet such conditions cannot produce satisfactory or correct results for modern demands. An attempt is sometimes made by such means so to adjust the tension of the spring and the shape and size of the orifices that the additional air admitted shall correct errors which creep in at high engine speeds. For all practical purposes, however, devices of this nature do not work well for any length of time.

The majority of multi-jet instruments have been provided with several jets of different dimensions, working in choke tubes of various sizes, so that for various engine demands either one or the other or a combination of jets comes into action.

Let us now for a moment consider the straight part of the curve for a circular orifice, such as will exist between the limits of about 5 in. and 20 in. of head for the type of orifice under discussion. These limits are quite usual in ordinary practice, but, of course, the modern engine runs the depression much higher than the upper limit here mentioned in many conditions of working.

We will take an experiment with water, which, as we know, is more viscous than petroleum spirit by 10 to 20 per cent. according to its temperature, as will be seen from Sorel's table, p. 53, and the author's experiments, which show approximately 15 per cent. increase of viscosity of water as compared with benzene.

TABLE XXIX.—CIRCULAR ORIFICE (DISCHARGE OF WATER).

Head.	Discharge.	Increment of Discharge.	
		By Experiment.	Air Theoretically through a Tube.
Inches.	Pints per hour.		
5	6	...	...
10	9	1.50	1.41
15	13	2.17	1.73
20	17	2.84	2.00

In the above the increase from 6 pints to 9 pints is 1.5 times the quantity, whilst, according to the law for air flow, the amount of air passing through a Venturi tube will vary as the square root of the increase of pressure difference. The pressure difference in this case is 2, *i.e.*, 10 in. is twice 5 in., and the square root of $2 = 1.41$.

If reference be now made to the author's characteristic curves for petrol flow, and the same sized orifice be taken, viz., 1.10 mm. diameter, and conversion be made into pints of fuel per hour instead of gallons, the following relations hold good :—

TABLE XXX.—CIRCULAR ORIFICE WITH PETROL AT 55° F.

Head in Inches over Orifice.	Pints of Fuel Discharged per Hour.	Increase of Discharge per cent. Compared with Water.	Increment of Discharge.	
			Fuel.	Theoretical Air through a Tube.
5	8.65	14.4	...	...
10	14.0	15.6	1.62	1.41
15	20.0	15.4	2.31	1.73
20	24.0	14.2	2.77	2.00

The differences in the third column are evidently due to slight experimental errors.

The discharge of fuel from the orifice is not directly proportional to the square root of the head, nor yet to any definite relation, as, for instance, it may

$$= c \times \frac{0.8h + \sqrt{h}}{2} \text{ where } c = 2.50,$$

or

$$= c \times \frac{0.25h + \sqrt{h}}{2} \text{ where } c = 5.$$

The former holds good for 10-in. and 15-in. heads, whilst the latter applies to 5-in. and 20-in. heads, for a jet orifice of 1.10 mm. diameter and 5 mm. long.

In order to bring the fuel discharge through various shapes of orifices into line the author calculates the discharge in gallons per hour per square millimetre of orifice, and this value is designated by the symbol $\frac{Q}{A}$, and from this can be found the coefficient of discharge of the orifice, as for example :—

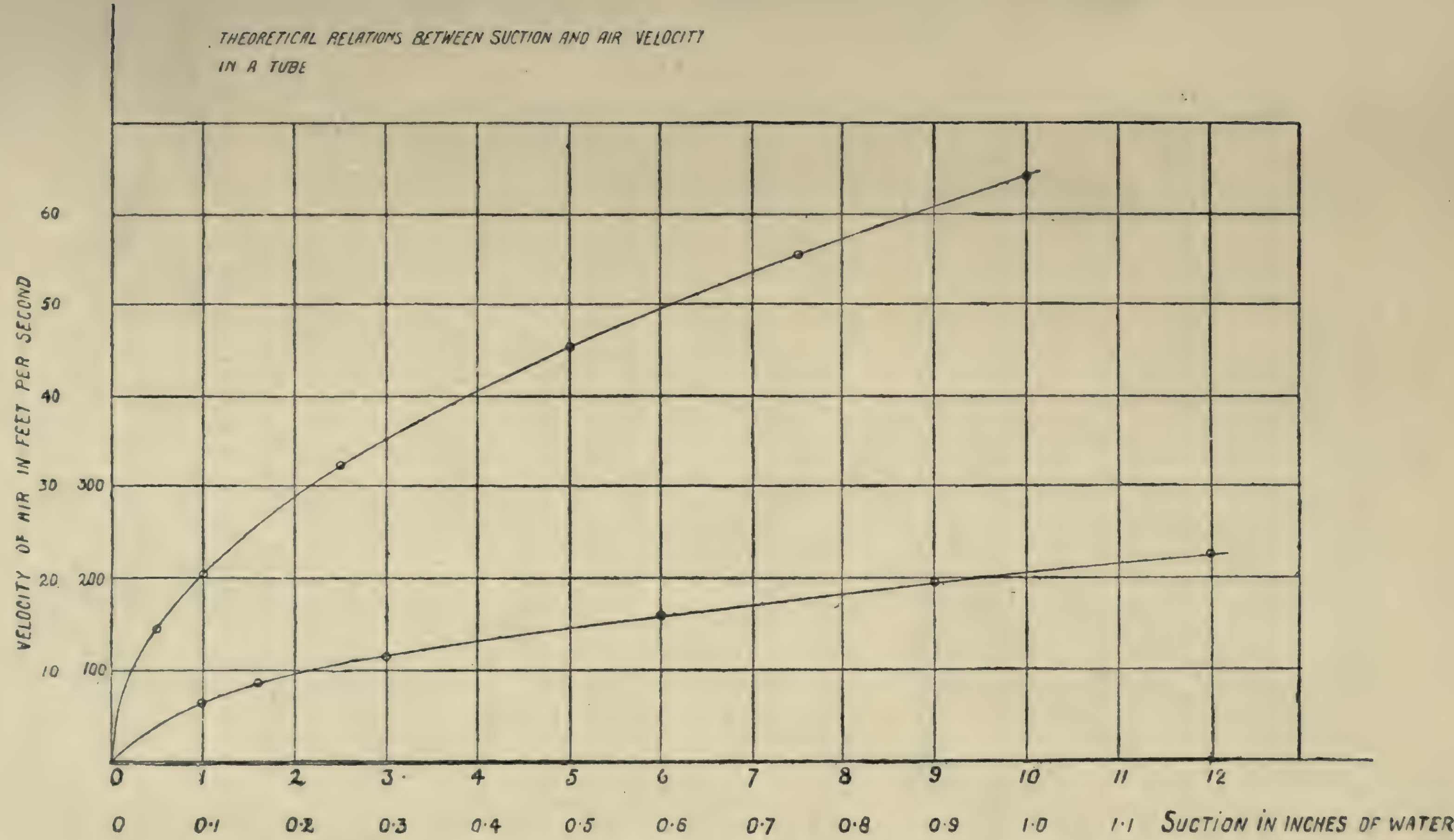

FIG. 7.—The two Curves are identical, one being drawn to ten times the scale of the other.

To find the coefficient of discharge c—

$$q = c\omega\sqrt{2gh} \text{ as before.}$$

Where Q = the discharge in cubic centimetres per second = Q (gallons per hour) × 1.26.

ω = area of the orifice in square centimetres $= \frac{A}{100}$

= head in centimetres.

$g = 981$ cm. per second per second.

For 10-in. head = 25 cm.—

$$c = \frac{q}{\omega\sqrt{2gh}} = \frac{Q \times 1.26}{\frac{A}{100}\sqrt{2 \times 981 \times 25}} = \frac{Q}{A} \times 0.568\,;$$

for 15-in. head = 38 cm.—

$$c = \frac{Q}{A} \times 0.463\,;$$

for 20-in. head = 50.8 cm.—

$$c = \frac{Q}{A} \times 0.400\,;$$

for 25-in. head = 63.5 cm.—

$$c = \frac{Q}{A} \times 0.356.$$

We will take now the flow of *water* through orifices as in the following table and find the coefficients of discharge.

TABLE XXXI.—CIRCULAR ORIFICES.

Water Flow in Gallons per Hour and Coefficient of Discharge of the Orifice.

Jet.		10-in. Head.		15-in. Head.		20-in. Head.	
Diameter, mm.	Area, Sq. mm.	Flow in Gallons per Hour.	Coefficient of Discharge.	Flow in Gallons per Hour.	Coefficient of Discharge.	Flow in Gallons per Hour.	Coefficient of Discharge.
1.10	0.94	1.12	0.680	1.63	0.800	2.13	0.906
1.15	1.04	1.56	0.855	1.78	0.795	2.19	0.842
1.20	1.13	1.85	0.930	2.25	0.925	2.62	0.930
1.30	1.32	2.38	*1.02	2.93	*1.03	3.50	*1.06

* Where the coefficient is above unity the result may be attributed to some slight experimental error.

CHAPTER VI

THE ANNULUS

The Annulus.—The modern development of carburettor practice along the lines of constant depression has led to the adoption of the annular orifice to a great extent.

When one comes to consider a varying orifice of this type scientifically, one has to deal with a problem of some importance and difficulty, for we find that with a pin of straight taper the increase in the area of the orifice is not proportional to the movement of the pin. Furthermore, we find that as the pin is gradually withdrawn from the orifice, the ratio of the length of the orifice to its effective area varies from moment to moment. For this reason a correctly designed modulating pin requires very careful thought and a large amount of experimental work. Even then grave errors are likely to creep in, due to the pin not lying centrally in the orifice. One cannot generalise a modulating pin design. We will, therefore, consider pins of 16 to 25 mm. long, fitting into orifices of 3.9 mm. to 3.96 mm. diameter, as with this type of pin the author has had considerable experience.

We will take as the first set of examples a pin 16 mm. long, 3.9 mm. diameter at the thickest end, and 3.45 mm. diameter at the tip, working in an orifice 3.8 mm. diameter. When water was passed through the orifice under a head of 10 in., the following rates of flow of fuel per hour and times for a discharge of half a pint were noted.

TABLE XXXII.

Pin 16 *mm. long and* 3.9 *to* 3.45 *mm. diameter.*

Position of Pin from Zero in mm.	Time for ½ pint—seconds.	Flow of Water in gallons per Hour.	Area of Annulus, sq. mm.	Gallons per Hour per sq. mm.	Coefficient of Discharge of the Orifice.
5	630	0.36	0.865	0.415	0.244
6	400	0.56	...	...	...
7	290	0.75	1.175	0.64	0.376
8	235	0.98	...	...	...
9	195	1.18	1.49	0.79	0.464
10	165	1.38	...	...	...

This flow, it will be seen, is remarkably small, and is due to the high jet friction ; also it will be noted that the coefficient of discharge of the orifice increases as the time of discharge decreases.

Let us now consider a modulating pin 18 mm. long, 4.05 mm. diameter at the root, and working in an orifice 3.96 mm. diameter, and again the same pin working in an orifice 3.80 mm. diameter. The pin in this case was marked off in intervals of 2 mm., and at each position experiments were made on the rate of flow of fuel in gallons per hour, and calculations deduced therefrom. Water was used as the liquid, with a pressure head of 10 in. over the orifice. Table XXXIII. shows the results obtained.

An attempt was made in designing the above pin to produce a flow of fuel as nearly as possible in proportion to the flow of air, and it was so set in the orifice that in normal zero its position was 2.5 mm. from the root, *i.e.*, the area of the annulus in the slow running position was 0.6 sq. mm.

This pin was designed by the author for a suitable carburettor for a 3-litre engine, and its effect is shown in the following curve.

TABLE XXXIII.—SPECIAL PIN 18 MM. LONG, WITH INCREASED TAPER, STARTING 10 MM. FROM THE ROOT. Diameter, 4.05 mm. at root, and 3.06 at tip.

Diameter of Jet, 3.96 *mm.*

Position of Pin in mm. from the Root.	Area of Annulus, sq. mm.	Flow in Gallons per Hour.	Gallons per Hour per sq. mm. of Area	Coefficient of Discharge of the Orifice.
0.5	zero	...	...	...
2.0	0.5	1.22	2.44	1.39*
4.0	0.90	1.41	1.57	0.89
6.0	1.40	1.80	1.28	0.725
8.0	1.80	2.02	1.21	0.635
Diameter of Jet, 3.80 *mm.*				
8.0	0.8	0.55	0.69	0.390
10.0	1.1	1.21	1.1	0.625
12.0	1.9	2.0	1.05	0.595
14.0	2.6	2.8	1.07	0.610
16.0	3.3	3.46	1.05	0.595
18.0	4.0	4.1	1.03	0.585

This curve and diagram show first of all a sweeping line from the left-hand top corner to the lower right corner, representing the time taken for a measured quantity of fuel to flow through the orifice in different positions of the pin, and it will be at once apparent that the initial increments of orifice opening show rapid increases in the fuel-flow. However, when the pin has lifted about 5.5 mm. the curve tails off, or in other words, the fuel-flow does not increase rapidly enough, and the characteristic of fuel-flow for this type of orifice shows a decided droop as the size of the orifice increases. In order to overcome this ten-

* This value appears to be exceptional, and must be considered with caution.

dency the modulating pin must be modified in shape,

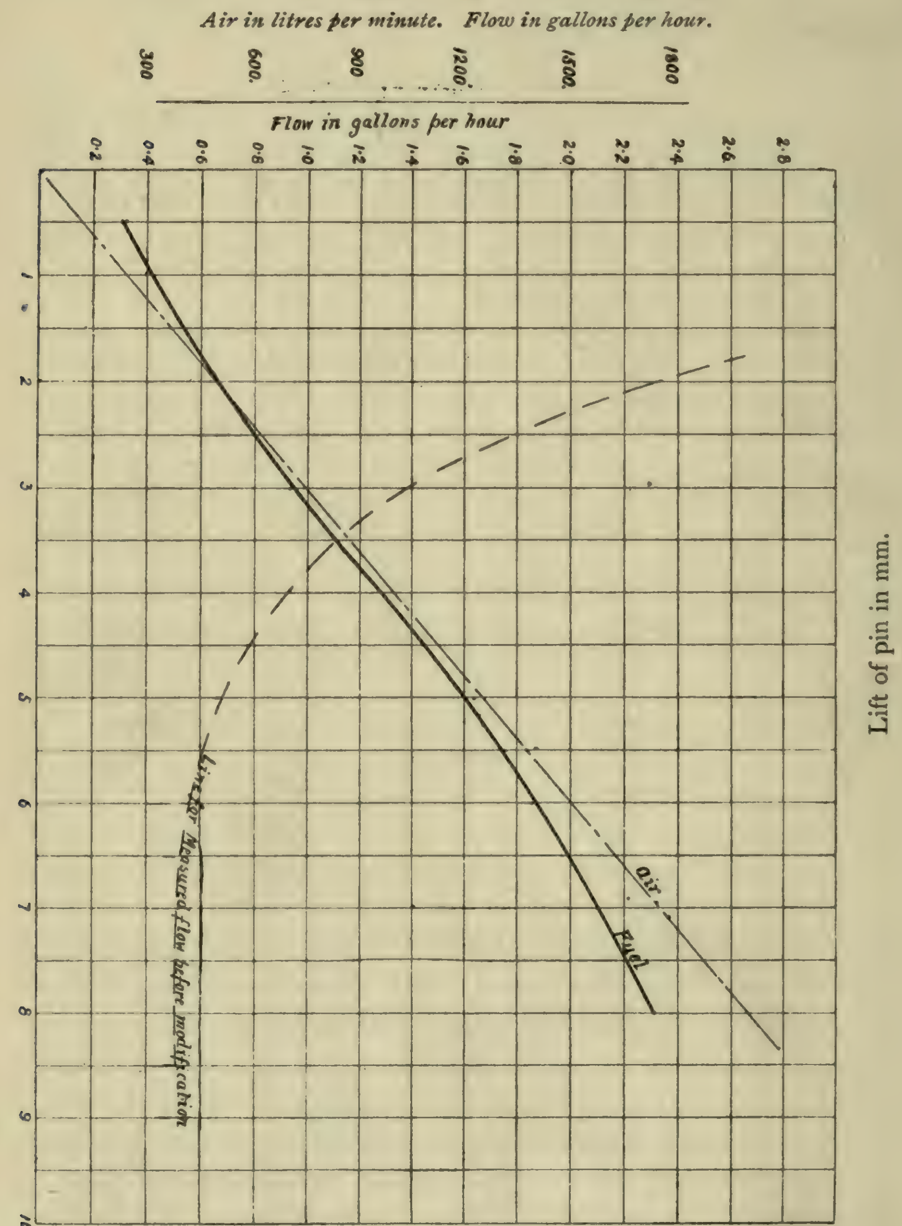

FIG. 8.—Curve of Fuel discharge through Annulus 3-litre Engine.

and the time curve was taken before the pin was so modified.

Passing now to the desiderata of the pin, an air curve is plotted to some convenient scale of ordinates so that the air passing will correspond correctly with the fuel required.

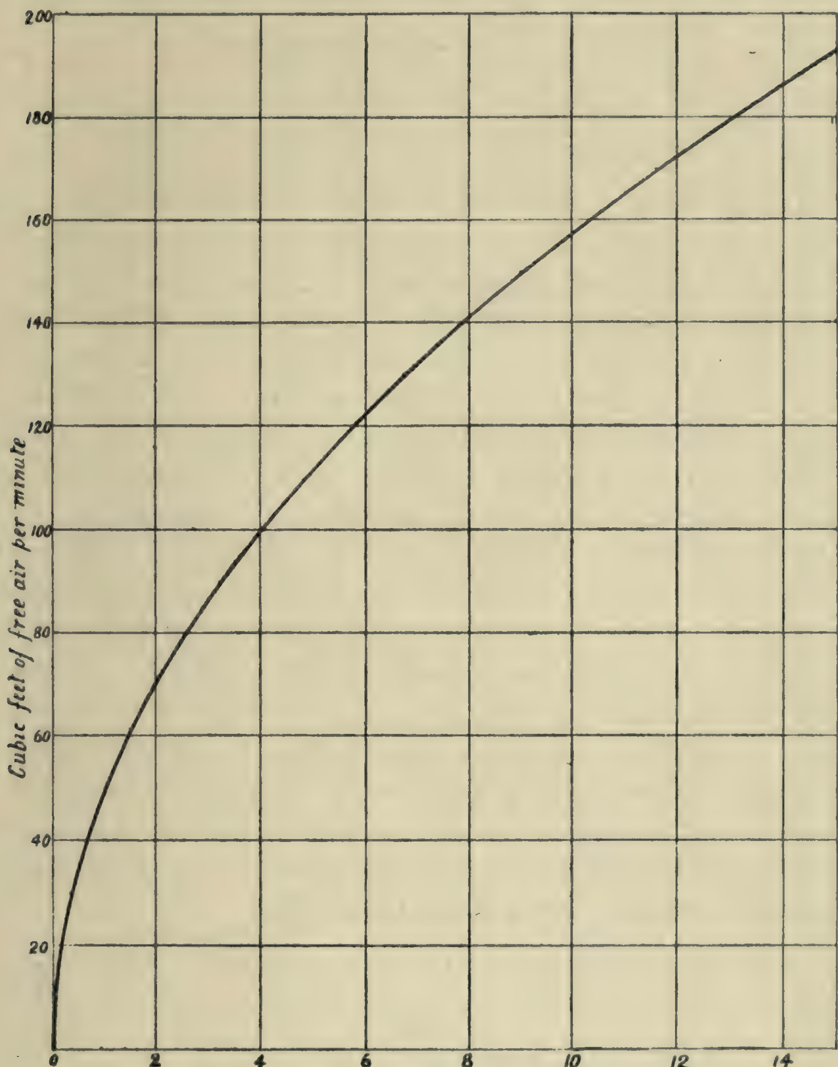

FIG. 9.—Flow of Air through $1\frac{1}{2}$-inch Venturi Meter.

Take, for example, a 3-litre engine: we find that for 100 per cent. volumetric efficiency at a speed of rotation of 1,000 revolutions per minute 1,500 litres of air and vapour pass through the engine.

For convenience and ease of calculation we will neglect the volume of the vapour and take as a round figure 10,000 volumes of air to 1 volume of liquid fuel. Then we find that the fuel required per minute is :—

$$\frac{1500 \times 1000}{10,000} = 150 \text{ c.c. per minute,}$$

$$\frac{150 \times 60}{4540} = 1.98 \text{ galls. per hour.}$$

It will be seen from experiment that this flow is given with a pin lift of 6.5 mm., but for convenience of the air scale, and in order to separate the air and fuel curves, a scale has been taken for the air curve which slightly foreshortens it and increases the inclination of the air curve. It is obvious, however, that the mixture will be slightly on the weak side at high speeds unless, of course, the suction is increased by fitting a suitable stop to prevent the air valve rising above a certain maximum. The author has, therefore, found it advisable in some instances to fit such a stop so as to limit the lift of the air valve to 8 or 10 mm. as the case may be, so that a sufficient flow of fuel will be provided when high engine speeds are required. Another method of attaining this end is to choke the air inlet aperture so that the depression within the instrument will be increased under high speeds of working of the engine.

We will consider for a moment a few figures taken from a careful test with such a carburettor, not in any way specially prepared but a stock instrument.

TABLE XXXIV.—FULL LOAD.

Revs. per Min.	Diameter of Pin.	Area of Annulus.	B.H.P.	Fuel Consumption	Pints per B.H.P. Hour.	Lift of Valve	$\frac{Q}{A}$	Coefficient of Discharge.
	mm.	Sq. mm.		Pints per Hour.		mm.		
500	3.80	0.94	8.25	10.5	1.27	2.3	1.40	0.795
1,000	3.61	2.08	19.5	16.95	0.87	5.0	1.02	0.568
1,800	3.40	3.22	26.1	21.9	0.84	8.0	0.85	0.483

The size of the engine is not given, but it is a standard type by one of the best known English firms with reasonable valve dimensions.

The fuel consumption was high, as the engine was a new one and rather stiff.

TABLE XXXV.—HALF LOAD.

Revs. per Min.	Diameter of Pin.	Area of Annulus.	B.H.P.	Fuel Consumption	Pints per B.H.P. Hour.	Lift of Valve.	$\frac{Q}{A}$.	Coefficient of Discharge.
	mm.	Sq. mm.		Pints per Hour.		mm.		
500	3.86	0.55	4.13	6.95	1.68	1.5	1.58	0.90
1,000	3.75	1.25	9.75	12.0	1.23	3	1.20	0.68
1,800	3.61	2.08	13.05	15.6	1.20	5	0.94	0.534

The examples given for the flow of fuel in the above table are typical of many figures obtained, and may perhaps be amplified by the following, taken from the same series of tests with a slightly different shape of pin.

TABLE XXXVI.

Area of Annulus, sq. mm.	$\frac{Q}{A}$.	Coefficient of Discharge.	Area of Annulus, sq. mm.	$\frac{A}{Q}$.	Coefficient of Discharge.
0.94	1.58	0.895	3.10	0.882	0.500
1.72	1.00	0.568	3.22	0.85	0.483
2.08	1.02	0.580	4.64	0.645	0.36
2.44	1.03	0.587	5.20	0.607	0.34
2.54	1.02	0.580			

It may be interesting to the reader to study an example of the results obtained by the author in America with a carburettor given to him to develop at the laboratory of the Automobile Club, New York.

As received the instrument was very erratic, and would

not work, although a great deal of time had been spent upon it by American engineers.

The author started by calculating, on a purely theoretical basis, the sizes of the air orifices and the dimensions of the tapered modulating pin, and personally constructed those parts in the laboratory, the whole work occupying one day. On the following day, the carburettor was attached to the engine, and without any trial and error adjustment the following authoritative results were obtained :—

TABLE XXXVII.

Tests on Carburettor in New York.

Engine Revs. per Minute.	Dynamometer Force in lbs. at the End of the Arm.	B.H.P.	Weight of Fuel per Hour. lb.	Weight of Fuel per B.H.P. Hour. lb.
405	37·1	8.57	8.8	1.03
1,012	39·1	22.6	15.2	0.672
1,300	35·9	26.7	16.9	0.632
1,620	30.7	28.4	18 0	0.635
1,830	27.5	28.7	19.6	0.683

From the above table the fuel consumption results will be seen to be entirely satisfactory for American gasolene, especially when compared with the majority of results obtained with American carburettors in the same laboratory, none of which had shown such a low consumption.

Before leaving the subject of the taper pin we will take a limiting case, assuming the hole has a diameter D = 8 mm.

$$\text{The pin has a diameter } \left.\begin{aligned} d_1 &= 7 \text{ at } 2.5 \text{ mm.} \\ d_2 &= 6 \text{ ,, } 5 \text{ mm.} \\ d_3 &= 5 \text{ ,, } 7.5 \text{ mm.} \\ d_4 &= 4 \text{ ,, } 10 \text{ mm.} \\ d_5 &= 3 \text{ ,, } 12.5 \text{ mm.} \end{aligned}\right\} \text{from the root.}$$

The respective areas of the annular orifices will be in proportion to the difference of the squares of the diameter of the pin at any position, and that of the orifice multiplied by $\frac{\pi}{4}$, which we will write K. For any other sizes of orifices the fuel area will be some function f of the areas here calculated.

$$\begin{array}{lll}
\left.\begin{array}{l}D=8\\ d_1=7\end{array}\right\} & \text{then } A=(64-49)K=15K & \\
 & & 13K \\
\left.\begin{array}{l}D=8\\ d_2=6\end{array}\right\} & \text{then } A=28K & \\
 & & 11K \\
\left.\begin{array}{l}D=8\\ d_3=5\end{array}\right\} & \text{then } A=39K & \\
 & & 9K \\
\left.\begin{array}{l}D=8\\ d_4=4\end{array}\right\} & \text{then } A=48K & \\
 & & 7K \\
\left.\begin{array}{l}D=8\\ d_5=3\end{array}\right\} & \text{then } A=55K &
\end{array}$$

If the air valve opening is proportional to its lift it will be seen that by the above reckoning the increment of fuel-flow is a great deal slower than the increment of air-flow under the same conditions in all cases. However, when the air valve opening is small, the coefficient of flow of the air orifice must be taken into account, as a greater valve area will be required to pass through the quantity of air, and this increase of air opening will also give an increase of fuel opening.

If, however, we write A as the air opening at a 10 mm. valve lift, and c as the coefficient of discharge of the air orifice, we have the following table for comparison and upon which to base the design of the air orifice.

In practice, when the valve is large, it will be found that its lift is practically proportional to the demand of the engine, so we may write :—

TABLE XXXVIII

Lift.	Fuel Area.	Air Area.	Coefficient of Discharge of the Fuel Orifice.	Fuel Discharge.
mm.				
2.5	f 15	0.25 A	0.900	f 13.5
5.0	f 28	0.5 A	0.725	f 20.4
7.5	f 39	0.75 A	0.635	f 24.8
10.0	f 48	1.00 A	0.600	f 28.8
12.5	f 55	1.25 A	0.550	f 30.2

The area of annulus is proportional to the square of the lift of a V-shaped measuring device.

CHAPTER VII

BREWER'S FUEL ORIFICE

HAVING now considered the fuel discharge from a circular orifice, and from an annulus, it is evident that in both systems there are certain defects which are difficult to overcome in practice. For this reason, the author carefully studied how it would be possible to design an orifice that would give a rate of fuel discharge closely approximating the flow of air through an aperture of ordinary formation, that is to say, that the flow of fuel should, as nearly as possible, approximate to the square root law or the discharge curve should be similar to that which is shown for the flow of air on p. 71.

The author considered that it was possible to design an orifice which would combine the characteristics of the circular hole and the annulus, *i.e.*, instead of the flow of fuel tending to increase (as shown by the curve having an upward trend) in the case of the round hole, and tending to lag (as shown by the curve's downward trend) in the case of the annulus, a composite orifice could be formed, so that the rate of flow of fuel would be a mean between the two. At the same time the orifice would produce a high friction, and give a low and practically constant coefficient of discharge under all ordinary working conditions. With this object in view, the first point to be considered was whether the orifice should be vertical or inclined, and furthermore whether a modulating pin of any particular shape and position would be necessary. The author decided that a modulating pin which was hanging in a vertical position would be the most suitable, and that this pin should not be liable to cause any error through

displacement in the orifice. For this reason he decided that the modulating pin should at certain points touch the orifice, or nearly do so, and should always be located within the orifice, so that it would not be liable to displacement under any set of conditions. Furthermore, it was considered necessary that any adjustment of the modulating pin should, if desired, be made whilst the engine was running, and that this adjustment should in no way entail any risk of leakage of air or fuel.

In many systems of modulating pins in carburettors it is only possible to make adjustments to the pins by dismantling the carburettor, or by screwing some device or holder into a gland which is more or less petrol tight. Such an arrangement is bound to be inconvenient, particularly as, when it is in an inaccessible position, it is impossible to see the amount of adjustment which has been given, or the amount of movement imparted to the pin as the carburettor works. In such a delicate arrangement as a carburettor adjustment, it is a *sine qua non*, first, that the adjustment should be visible, and second that it should be accessible. It should also be possible to locate the adjustment at any time so that in the event of the carburettor being taken down, or being deranged by an inquisitive chauffeur, it is an easy matter to fix the adjustments in their original or predetermined condition without loss of time and with a maximum of accuracy. Having all these points in view, the author decided, first, that no system in which the modulating pin passed through the fuel path would be feasible, and second, that the only system possible would be one with the pin hung in a vertical position and readily accessible without in any way interfering with any of the arrangements of the carburettor itself. With these objects in view the author has designed a modulating pin which is shown on pp. 88 and 163, and which has the following characteristics. First, the coefficient of discharge of the orifice is practically constant under all working con-

ditions, *i.e.*, whether within the limits of working the head is small or great. Second, in any position of the pin, whether the orifice is large or small, the coefficient of discharge is not affected to any noticeable extent. Third, the jet friction is high, and thus the effect of inertia is counteracted to a very considerable degree. Fourth, when the pin is in a neutral position, or when the throttle is suddenly closed, the pin automatically falls back in the orifice and prevents any excessive flow of fuel which might otherwise ensue (due to the inertia of the fuel itself in the fuel passage). Fifth, the zero position of the pin can be absolutely and easily determined, as whatever adjustment of the carburettor is made for various proportions of mixture, the zero position can be always returned to, and is unaffected. Sixth, the pin can be taken out of the carburettor without any loss of fuel, and it can be dismounted with a minimum of effort in a few seconds. If it is desired to make any alteration to the pin, or to change it, this can be done by hand without the use of tools, and a new pin can be substituted in a few seconds. Seventh, the pin is a good size, and in using a large pin it is much easier to work upon it and to make any adjustments than would be the case where a very small pin is employed. Eighth, the surface of such a pin is large, and therefore the wear, if any, is distributed over a large area of contact, though in this case the surfaces are not actually in contact, but are separated by a film of liquid.

If we look into the theory of this particular type of orifice, we must embody with the shape of the pin its surroundings and working conditions, and combined with this pin is a jet tube of ample dimensions, having an exterior formation as shown upon the drawing. This exterior formation, in combination with a small Venturi tube, forms a very important feature of the Brewer carburettor, which is the atomising of the fuel as it issues from the jet. The atomising is carried out by concentrat-

ing the air flow in the vicinity of the fuel orifice at all times, and so arranging the Venturi tube that within certain limits of working this concentration is carried out, as the minimum area between the Venturi tube and the exterior of the jet tube is located round the largest part of the jet tube, until such a time as the Venturi tube lifts above the jet tube to a distance which makes the annulus between the Venturi tube and the modulating pin smaller than that between the Venturi tube and the exterior of the jet tube. This is somewhat difficult to explain, but it can easily be shown mathematically, and it is important that until a predetermined limit of working is reached, a high velocity of air be concentrated round the jet. When a tendency occurs for the jet to over-discharge under a high velocity head the area around the jet is increased. Only sufficient air is allowed to pass through the Venturi tube and round the jet tube in ordinary working, to produce slow running of the engine and car speeds on the level up to about 10 miles per hour. It is at such a speed that in a two-jet carburettor the smaller jet is in operation. To obviate the necessity of a number of jets this internal Venturi tube arrangement is resorted to. By means of it a very fine spraying of the fuel is possible, and the issuing stream of fuel passes up the centre of the air valve and is deflected by the deflector plate on the modulating pin carrier and throughout the mixing chamber of the carburettor. When, however, the engine demand increases, that is when the depression within the mixing chamber has reached about 10 in. of water head, and the fuel curve of an ordinary single-hole jet orifice begins to flatten out, the carburettor works in the usual way, proportioning the fuel orifice to the air orifice, and so on throughout the range of working until the upper limit is reached. When, however, this point is arrived at, a certain important law is brought into requisition, and if one study the question of vapour pressure in Chapter II. one will see that as a mixture becomes richer its vapour pressure increases. It is therefore intended in

this arrangement, where fuel is vaporised in the centre of an air valve, to take advantage of the increase of vapour pressure at such times as the vapour pressure tends to increase, due to the tendency to enrichment of the mixture. For instance, supposing there is a depression equal to

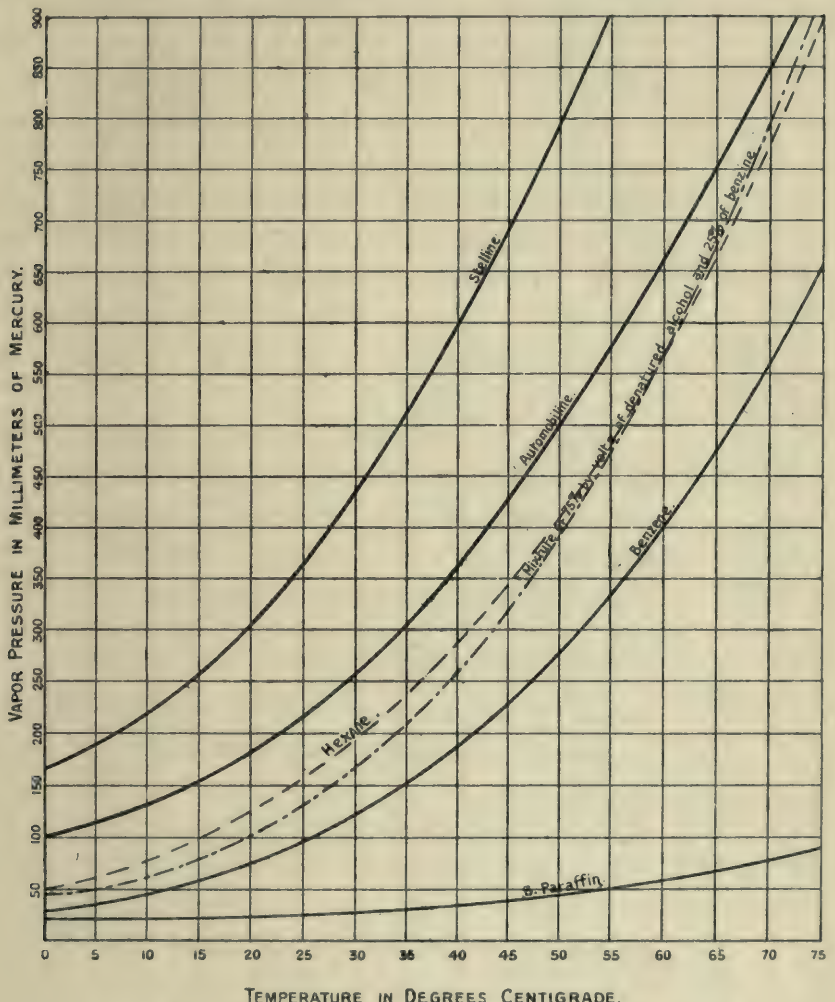

FIG. 10.—Curve of Vapour Pressure for Saturated Vapours.

25 in. of water head in the mixing chamber of the carburettor, it does not follow that this pressure is actually operative at the jet orifice, as the pressure at this point is due to the difference between the negative pressure in

the mixing chamber and the positive pressure which is due to the vapour pressure of the fuel. Of course vapour pressure only can occur where vapour occurs, and in designing this carburettor the amount of air which is allowed to pass primarily around the jet is small, about 10 to 18 per cent. of the total when the air valve is in operation, thus causing the vapour which comes up the centre of the air valve to be more or less saturated. The extent of the saturation will usually depend upon the temperature of the air which is admitted around the small Venturi tube. With this object in view the carburettor has been so designed that a specially hot-air supply can be introduced to this portion of the instrument, and hot air can be taken from any desired position.

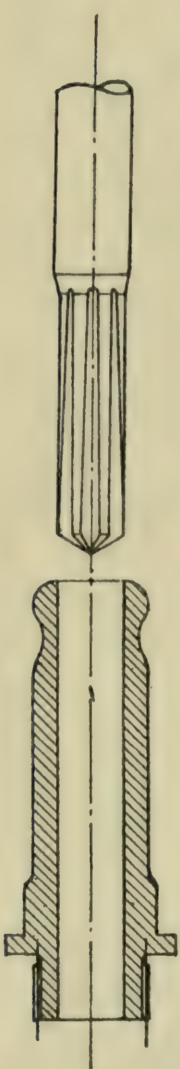

Fig. 11.

It is not intended in this chapter to discuss the question of the carburettor or its merits, but simply the effect of the orifice, and this is all bound up in the question of vapour pressure as well as in that of the coefficient of discharge. Now with reference to this coefficient, we will for a moment study a few figures to show how the size of the fuel apertures are arrived at, and it may be mentioned that an important feature of this type of orifice is the exact shape of the flutes which are formed in the sides of the modulating pin. These flutes, instead of being of an ordinary V shape or slits, are formed of a semicircular section with rounded corners where the flutes run out into the circumference of the modulating pin. At the upper end of the fluted part a slight taper is given to the pin so as to deflect the fuel stream, and at the same time to give a positive position for slow running.

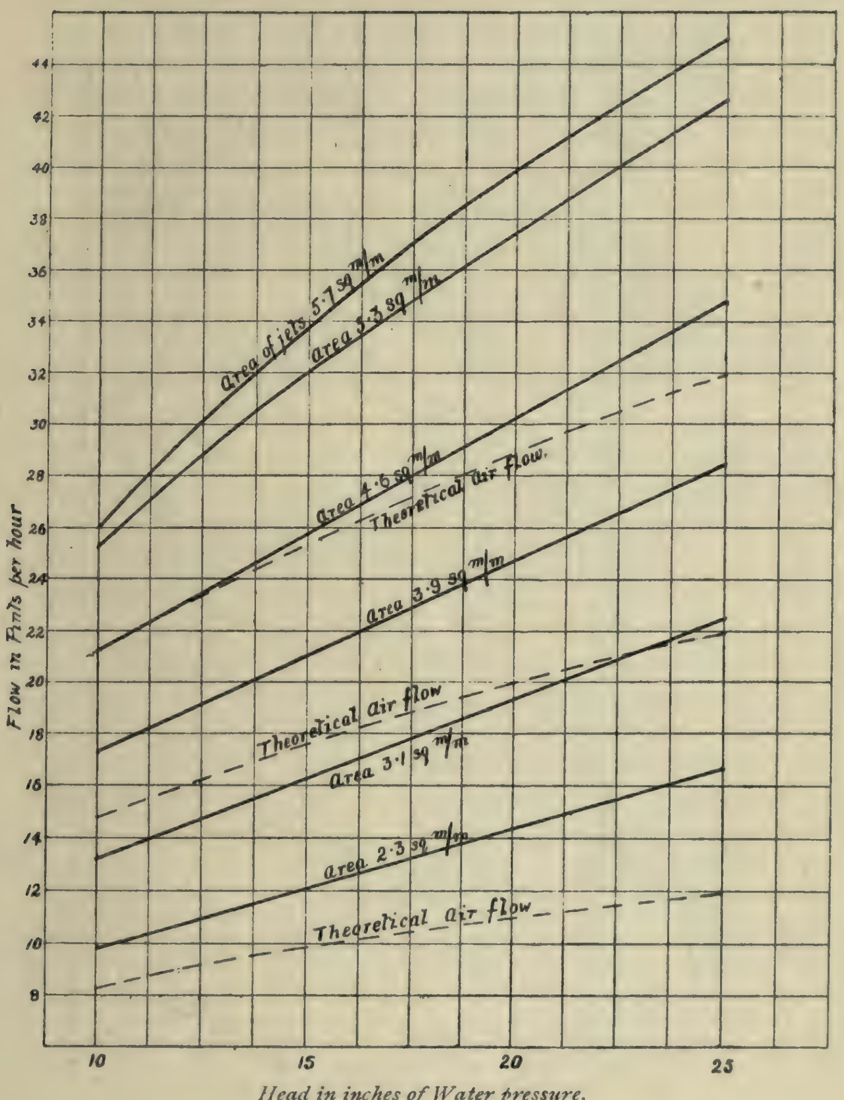

FIG. 12.—Flow of Water through Brewer Orifices.

TABLE XXXIX.—WATER-FLOW IN GALLONS PER HOUR PER SQUARE MM. OF ORIFICE AREA.

Lift of Pin in mm.	Area through Flutes in sq. mm.	10-in. Head.			15-in. Head.			20-in. Head.			25-in. Head.		
		Gallons per Hour.	Flow per sq. mm.	Co-efficient of Discharge.	Gallons per Hour.	Flow per sq. mm.	Co-efficient of Discharge.	Gallons per Hour.	Flow per sq. mm.	Co-efficient of Discharge.	Gallons per Hour.	Flow per sq. mm.	Co-efficient of Discharge.
6	2.3	1.21	0.523	0.297	1.5	0.652	0.302	1.78	0.775	0.310	2.05	0.893	0.318
8	3.1	1.65	0.532	0.302	2.08	0.674	0.312	2.36	0.760	0.304	2.8	0.905	0.322
10	3.9	2.16	0.550	0.312	2.7	0.695	0.322	3.1	0.795	0.318	3.54	0.905	0.322
12	4.6	2.65	0.576	0.327	3.25	0.708	0.328	3.75	0.815	0.326	4.35	0.945	0.336
14	5.3	3.15	0.593	0.337	4.0	0.755	0.35	4.6	0.862	0.345	5.3	1.00	0.356
15	5.7	3.25	0.572	0.325	4.05	0.71	0.328	5.0	0.875	0.350	5.55	0.98	0.350

These tests were made with a fluted orifice previous to modification.

TABLE XL.—CALCULATION OF AREA OF ORIFICE (BREWER'S PATENT SYSTEM).

Revs. per Min. of Engine.	Air Velocity, 200 Ft. per Sec.			Lift of Modulating Pin.	Area through Flutes.	Flow of Fuel.
	Fuel Required.	Circular Orifice.	Annular Orifice.			
	Gals. per Hour.	Area Required. Sq. mm.	Area Required. Sq. mm.	mm.	Sq. mm.	Gals. per Hour.
500	0.99	0.5	0.90	as set	1.62	0.99
1,000	1.98	0.81	2.0	8.0	3.2	1.96
1,500	2.97	1.43	3.3	11.5	4.5	2.97
2,000	3.96	1.65	4.0	16.0	6.0	3.96

We see from the above table that the combined area of six flutes at a distance of 16 mm. from zero is 6 sq. mm.,

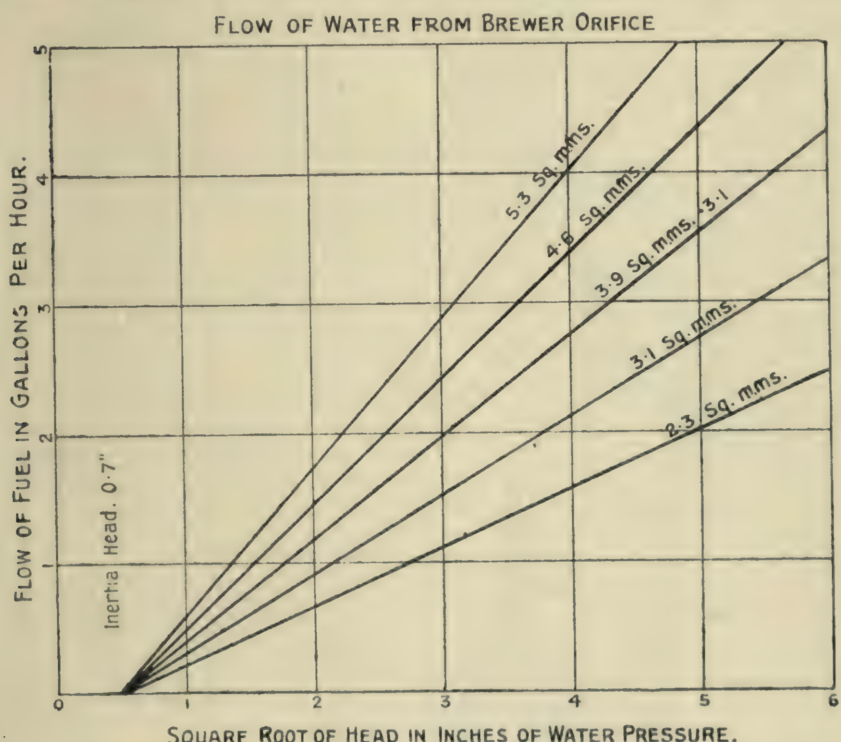

FIG. 13.

i.e., the area of each flute is 1 sq. mm. A sectional contour, plotting areas of orifice with linear movement, does not give a directly proportionate increase of area, as special provision has been made for ease of starting with cold fuel and air.

The following table is compiled from a series of curves, the result of experimental work both on positive pressure discharges through this type of orifice and from measured fuel consumptions of an engine on the test bench. In order to ascertain the area of the orifice, the pin position during the various tests was noted, and from an enlarged diagram of the flutes these areas have been calculated. The figures given are mean values, and experimental errors have been as far as possible allowed for.

The suction was measured directly by a water manometer, but in the pressure tests the fuel head was taken, due allowance being made for the specific gravity of the fuel.

TABLE XLI.—BREWER ORIFICE (TYPE A)—FLOW OF PETROL IN GALLONS PER HOUR, SP. GR. 0.720, AT 55° F.

Area Flutes.	1	1.96	3.25	4.85	6.75	9.0	11.5	14.4	17.6	19.4	25	Head, Inches of Water.
	1	1.4	1.8	2.2	2.6	3.0	3.4	3.8	4.2	4.4	5	$\sqrt{h}$
Sq. mm. 0.8	...	...	...	0.34	0.42	0.52	0.58	0.68	0.75	0.78	0.9	...
1.2	...	...	0.40	0.51	0.63	0.75	0.87	1.0	1.1	1.17	1.35	...
1.8	...	0.38	0.44	0.70	0.85	1.00	1.16	1.32	1.48	1.55	1.8	...
2.4	...	0.55	0.76	0.98	1.2	1.42	1.64	1.86	2.08	2.3	2.55	...
3.2	0.42	0.73	1.04	1.24	1.65	1.98	2.28	2.65	3.0	3.23	3.7	...
4.0	...	0.97	1.36	1.74	2.13	2.5	2.88	3.24	3.6	3.9	...	...
4.8	...	1.1	1.56	2.04	2.5	3.0	3.5	3.9	...	...	...	...
5.6	...	1.55	2.1	2.7	3.3	3.86	...	...	...	...	...	...

The equation to the curve for an orifice 2.4 sq. mm. in area is :—

$$y = m(x - c) \text{ where } c = 0.4,$$
$$m = \frac{2.55}{4.6} = 0.55,$$
$$y = 0.55(x - 0.4).$$

Area.	Tan. of Angle.	Flow, Galls. per Hour.
Sq. mm.		
5.6	1.48	1.48 $(\sqrt{h} - 0.4)$
4.8	1.15	1.15 $(\sqrt{h} - 0.4)$
4.0	0.965	0.965 $(\sqrt{h} - 0.4)$
3.2	0.785	0.785 $(\sqrt{h} - 0.4)$
2.4	0.55	0.55 $(\sqrt{h} - 0.4)$
1.6	0.39	0.39 $(\sqrt{h} - 0.4)$
1.2	0.234	0.294 $(\sqrt{h} - 0.4)$
0.8	0.195	0.195 $(\sqrt{h} - 0.4)$

To find the flow of fuel from a Brewer orifice when the area of the flutes is known, it has been found from experiments, with water as the medium, that with orifices whose areas for the combined six flutes varied between 2.3 sq. mm. and 5.3 sq. mm., the equation for the flow was—

$$Q = n(\sqrt{h} - 0.5).$$

Where Q is the flow in gallons per hour.

n is a constant depending upon the size of the orifice.

$\sqrt{h}$ = the square root of the water head over the orifice.

0.5 = the origin of the curves on the axis of x, and is a function of the inertia head.

For all practical purposes for orifices of the dimensions given above $n = \frac{A}{5}$, but increases slightly as the orifice increases in size.

As showing the combination of circumstances under

which any desired flow of fuel can be obtained we will take for examples flows of 1, 2, and 3 galls. per hour of water respectively.

Taking the same formula as above, we find there is a constant K which applies approximately for every flow within the above limits irrespective of the head or the area, this being 0.200 to 0.220, as will be seen from the following table taken from the curves of flow, and this constant multiplied by the expression $A(\sqrt{h} - 0.5)$ gives the flow in gallons per hour.

TABLE XLII.

Flow, 1 Gall. of WATER per Hour.

$\sqrt{h}$.	Area.	$A(\sqrt{h} - 0.5)$.	K.
Inches of Water Head.	Sq. mm.		
1.3	5.3	4.25	0.236
1.5	4.6	4.60	0.218
1.7	3.9	4.70	0.213
2.1	3.1	4.95	0.202
2.7	2.3	5.05	0.198
Flow, 2 Galls. per Hour.			
2.2	5.3	9.0	0.222
2.5	4.6	9.20	0.218
3.0	3.9	9.75	0.205
3.75	3.1	10.0	0.200
4.95	2.3	10.2	0.197
Flow, 3 Galls. per Hour.			
3.05	5.3	13.5	0.222
3.6	4.6	14.3	0.210
4.3	3.9	14.8	0.203
5.4	3.1	15.2	0.197

TABLE XLIII.

Flow, 1 Gall. of PETROL per Hour, sp. gr. 0.720, at 55° F.

$\sqrt{h}$.	Area.	A($\sqrt{h}$ – 0.5).	K.
Inches of Water.	Sq. mm.		
1.4	4.0	3.6	0.28
1.8	3.2	4.15	0.248
2.2	2.4	4.08	0.251
3.0	1.6	4.00	0.25
3.8	1.2	3.96	0.26
Flow, 2 Galls. of Petrol per Hour, sp. gr. 0.720, at 55° F.			
1.7	5.6	6.73	0.296
2.2	4.8	8.15	0.245
2.5	4.0	8.00	0.25
3.0	3.2	8.00	0.25
4.0	2.4	8.4	0.238
Flow, 3 Galls. of Petrol per Hour, sp. gr. 0.720, at 55° F.			
2.4	5.6	10.6	0.283
3.0	4.8	12.0	0.25
3.7	4.0	12.8	0.235
4.2	3.2	12.2	0.246

From the foregoing tables we see that within the limits of experimental error it is possible to determine the relations between fuel-flow, area of orifice, and suction at the orifice. We further note that the liquid-flow when petrol is used is greater than with water, in relation to the two approximate constants 0.250 and 0.220.

The experiments upon which these calculations are based were carried out both by means of direct fuel heads and also by measurements made with the carburettor attached to an engine on the test bench. Un-

doubtedly further research in this direction will bring to light many more interesting details, and time only will enable such research to be undertaken.

There is an interesting development of this type of orifice which is in practical use in the Brewer carburettor which in summary gives the following results :—

When the pressure difference is 15 in. of water-head the mean flow of petroleum spirit of 0.765 sp. gr. at 56° F. is 0.9 gall. per hour per sq. mm. of area of orifice, with a coefficient of discharge of 0.434.

As the pressure increases to 20 in. of water-head, the mean flow of fuel is 1 gall. per hour per sq. mm., with a coefficient of discharge of 0.440, whilst with a pressure of 25 in. of water-head the mean flow of fuel is 1.15 gall. per hour per sq. mm. of area of orifice when the coefficient of discharge is 0.466.

This increasing coefficient is provided for by means of the tubular formation round the orifice previously described.

TABLE XLIV.—BREWER ORIFICE.

The relations between area, $\sqrt{h}$, and the constant give to a certain flow of petrol under varying conditions.

	A.	h	$\sqrt{h}$	A $\sqrt{h}$
	Sq. mm.	Inches of Water.	Inches of Water.	
Q = 1 gall. per hour	4.7	1.7	1.3	6.15
	3.9	2.1	1.45	5.67
	3.1	3.0	1.72	5.34
	2.4	4.8	2.2	5.28
	1.8	9.0	3.0	5.4
	1.2	14.4	3.8	4.56
Q = 2 galls. per hour	4.7	4.4	2.1	9.9
	3.9	6.25	2.5	9.75
	3.1	9.0	3.0	9.3
	2.4	16.0	4.0	9.6
	1.8	30.0	5.5	9.9
Q = 3 galls. per hour	4.7	9.0	3.0	14.1
	3.9	13.0	3.6	14.0
	3.1	19.4	4.4	13.6
	2.4	33.5	5.8	13.9

FLOW OF SHELL SPIRIT FROM BREWER ORIFICE @ 55°F

FIG. 14.

For convenience of reference the following table gives the area of a fluted orifice cut with a V-shaped tool of 45° angle neglecting the rounding of the corners.

TABLE XLV.

Depth of Cut.	Width of Cut.	Area Through One Orifice.
mm.	mm.	Sq. mm.
0.5	0.2	0.10
1.0	0.42	0.42
1.5	0.62	0.93
2.0	0.83	1.65
2.5	1.05	2.61
3.0	1.25	3.75
3.5	1.45	5.07

It will be seen from the above table that a tip cut of slightly under 2 mm. deep and 0.83 mm. wide will give the necessary area. Such a shape is not, however, used in practice. In many instances it is preferable to allow the depression in the instrument to increase under conditions of maximum working for several reasons, the chief of which are that a carburettor is so seldom worked under these conditions, and it is more convenient to fit a smaller sized instrument which is sufficient to satisfy ordinary demands, and thus keep its cost down, as well as its dimensions. Furthermore, a slight sacrifice by doing this is really not of very great moment, except under special circumstances, and a carburettor of the Brewer type allows an increase of depression without impairing the quality and uniformity of the mixture. In passing it may be stated that by the use of a spring the otherwise large mass of the moving part is obviated, and this reduces the inertia of such a part.

CHAPTER VIII

SPECIAL JETS

Claudel.—This jet has been already referred to in connection with the flow of fuel through small orifices, but it should be noted that in the curves and figures of tests with this jet, the small screw at the end of the shrouding tube was removed. The flow curves are, therefore, only those of a plain circular orifice, and do not apply to this jet under working conditions.

The main feature of the Claudel jet is the shrouding tube, which is so situated that the holes at the lower end of it are in communication with the atmosphere in the carburettor inlet, the effect being that when the throttle is in a partially closed position, the actual suction operating at the jet orifice is less than the suction in the mixing chamber on account of the air leakage up the shrouding tube. Furthermore, the air thus leaking issues with the fuel stream through the upper series of holes in the tube, thus breaking up the fuel into a fine spray. This jet is essentially of the indirect suction type, and it is only at full throttle opening that the absolute pressure at both ends of the tube is approximately the same.

When the fuel stream issues from the jet orifice it is baffled by the point of a small screw, the effect being to restrict the surplus flow of fuel when the rate of discharge tends to increase above the theoretical amount. The shape of the tip of this screw is important, as also the distance of the tip of the screw above the fuel orifice, as the retardation depends upon the correct distance being maintained. The author has been able to obtain very

interesting results at Brooklands with small modifications of the jet orifice for racing purposes.

The special Claudel racing jet is a further advance in the development of this device, as it has been found that when a very large carburettor of this type has been fitted to racing cars, some slight difficulties may occur in the

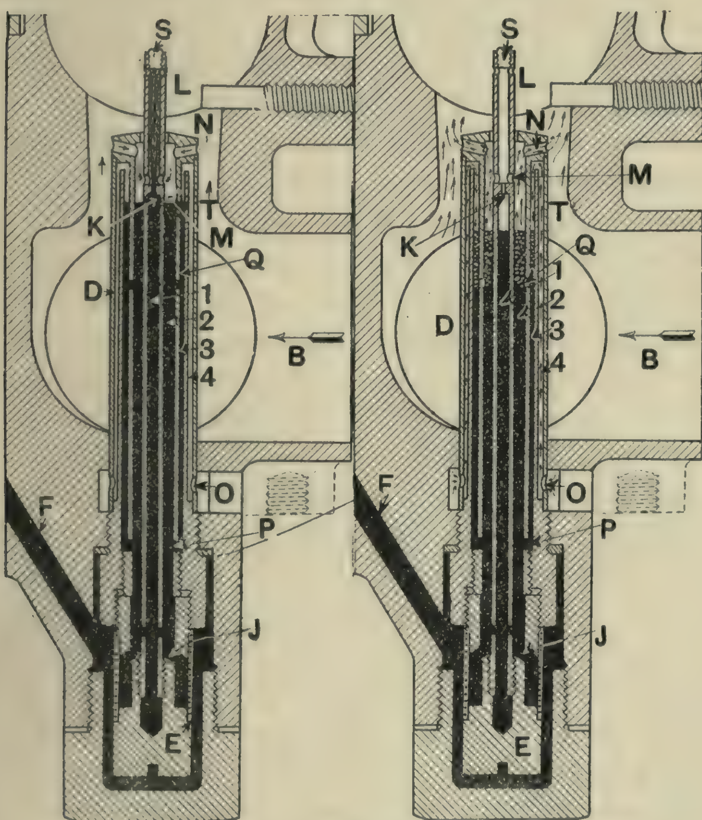

FIG. 15.—Claudel Jet.

ordinary way in connection with starting and slow running. The latest Claudel racing jet is provided with a special prolongation tube of small diameter, with a closed top and side orifices, and is carried upwards into the throttle barrel in contrast to projecting the whole jet into this space in the ordinary type. Three annular fuel columns are provided, the centre one being in communication with

the starting and slow running orifice, the necessary air entering through a series of holes in the upper end of the shrouding tube in such a manner that it issues with the fuel stream through the centre orifice. A by-pass is provided in the throttle barrel by which the vapour passes to the engine.

As the demand of the engine increases there is a reversal of flow through the upper series of holes in the outer shroud tube, as the air then passes in the usual manner through the lower series of holes in this tube, and descends a second annulus in which the fuel ascends, passing with the fuel outwards through the upper series of holes as in the ordinary Claudel jet.

As the fuel level descends in the jet, under full throttle opening, a series of holes in the base of the inner shrouding tube become uncovered, thus allowing a still further stream of air to pass with the fuel up the jet. The turbulence set up by this great rush of air, combining with that of the main air supply, causes a very fine atomisation of the fuel.

The great problem in a racing carburettor is to so arrange the jet that a copious supply of fuel is maintained in the vicinity of the jet orifice whilst the throttle is closed, so that when sudden acceleration is demanded, this fuel is readily discharged into the mixing chamber upon opening the throttle. This annular type of jet is so arranged that the fuel accumulates whilst the central jet only is at work, and is readily liberated when desired.

One other feature is interesting in connection with this instrument, and it will be noticed that a practically true Venturi formation is given to the passage for the gas by reason of the taper through the throttle barrel and the prolongation of the outlet.

Solex Jet.—The new type of jet fitted to the Solex carburettor is also of the annular type, and is shown in Fig. 16, and it will be seen that it consists of three pieces—a centre tube with a conical seat forming the measuring device; a main casing containing the same, screwed into

the carburettor body; and an outer cover attaching the whole together in the form of a single unit. The inner tube, as also the outer case, have each two holes pierced in their sides near the base, those in the centre tube becoming uncovered by the fuel when the flow increases under high engine suction. This drop in fuel level is due to the hole in the base of the centre tube being smaller than that at the top, and when the fuel level descends, an air stream passes upwards and then downwards through the two annular spaces, and mixes with the fuel stream from the centre jet.

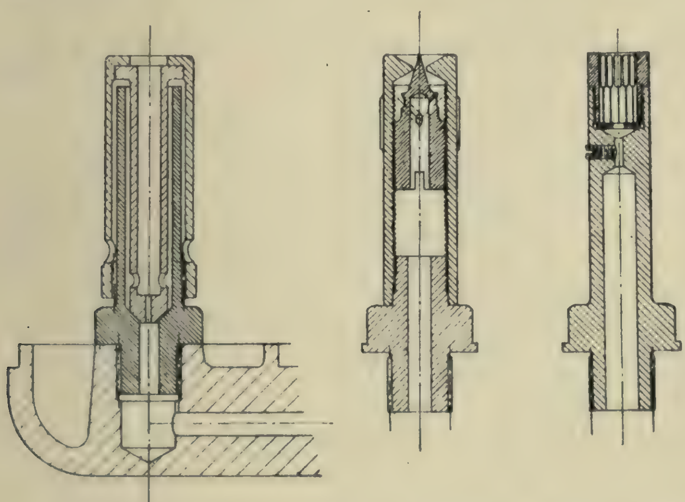

FIG. 16.—Solex. FIG. 17.—Mills. FIG. 18.—Javal.

Mills Jet.—This device can be fitted to many of the standard jet carburettors, its object being to produce a greater atomisation of the issuing stream of fuel than is generally possible with a plain hole. Fig. 17 shows one form of this jet whose characteristic is a spraying cone, possible of regulation as regards the effective area between it and a spraying nozzle, to which it is adjacent.

The nozzle closely represents that type originally used for oil in connection with the Priestman oil engine, and whose properties are well known. The internal conical regulator is a convenient method of producing any desired

fuel-flow, as it can be screwed into any desired position relatively to the aperture of the spraying nozzle when the jet tube is dismounted. Once in position no further regulation need be made, except for variations of temperature or fuel. There is no doubt as to the efficacy of such a device when properly regulated, as the spraying properties are great, but it must be understood that this jet is not automatic in the sense that it has any effect upon the efflux of fuel at any particular suction.

The Javal Jet is another type of spraying device, consisting of an ordinary jet orifice fitted with a regulating screw, upon which is superposed a spray chamber. This chamber is fitted with a number of small metallic cylinders, each attached to a fine wire, so that the whole resembles a small brush. The complete outer end of the spray chamber is filled with these metal cylinders closely packed together, so that the fuel space is formed by the interstices between the cylinders. It will be seen that the device is applicable to many standard jet carburettors, and it should have a beneficial effect upon the action of the instrument, but up to the time of writing the author has no definite figures upon this point.

The Holley Jet is of American design, its object being to obtain automaticity at high suctions by means of the admixture of air with the issuing stream of fuel.

The jet is cup-shaped, and sits in a similar formation in the carburettor body, there being an annular space between the jet and its container. Two holes are drilled through the container wall, one near its base to admit the fuel from the float chamber to the jet, and one higher up connecting with the float chamber, but submerged under ordinary conditions of running.

When, however, the level of the fuel in the float chamber falls under high engine demands, the upper hole communicates with the air in the float chamber, and allows a certain proportion of that air to pass through the jet with the fuel.

The jet orifice is controlled by an adjustable needle

valve, and situated immediately above the orifice is a very small choke tube. This tube varies in design and position for four or six cylindered engines.

Jets with orifices in the side are exemplified by the Sthenos (French) and Locomobile (American). The former is shown in Fig. 20, and has two holes drilled at the opposite ends of a diameter near the top of the jet tube. The gradation of nozzle size is arranged by drilling, say,

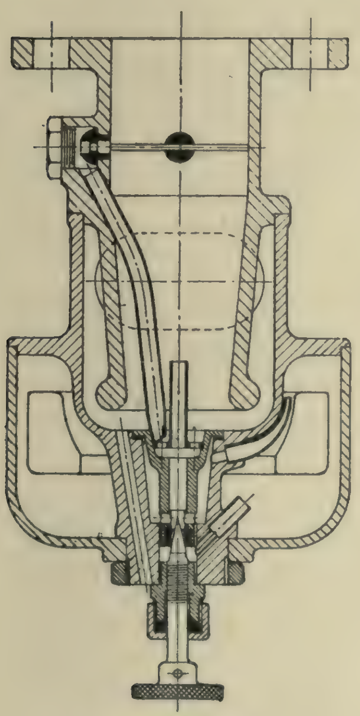

FIG. 19.—Holley.

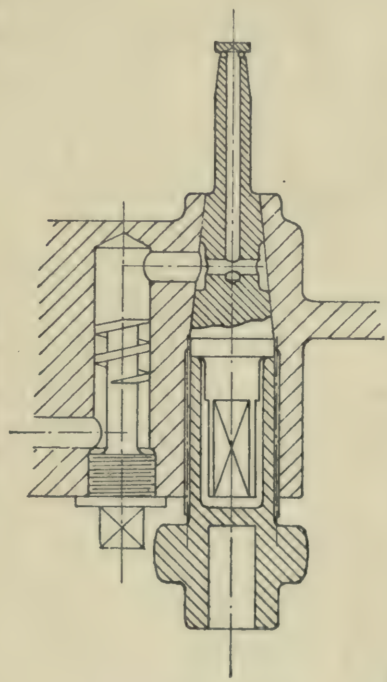

FIG. 20.—Sthenos.

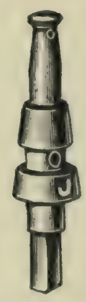

FIG. 21.—Sthenos Jet.

two holes of the same size, the next larger orifice having an increase of dimension to one hole only, then both holes alike of the larger dimension, and so on.

Thus very fine gradations can be arrived at.

The Locomobile orifices are also two in number, one being high up in the jet tube, the other lower down.

The lower hole only supplies fuel at low suctions, but when the motor speed increases fuel issues from the upper orifice in addition.

CHAPTER IX

MOVING PARTS

CONSIDERING the modern carburettor designs in a broad sense, we must come to the conclusion that one of the principal differences between the American and the European carburettor consists in the almost general adoption of moving parts in the American design as distinct from their elimination in the majority of European practice.

What the American carburettor manufacturer relies upon is some manipulation of the air supply by means of a suction operated valve, whereas the European designer has a leaning towards the system of compensating jets.

This generalisation must only be considered in a broad sense, because there are numerous exceptions on both sides of the Atlantic. As an instance, the Holley instrument shows progress in the European line of thought, in that moving parts are eliminated, and the jet orifice is so designed that, under certain working conditions, the air is allowed to pass through the jet orifice together with the fuel. The flow of fuel is thus retarded when high suction is present in the body of the instrument. As an alternative to the problems attendant upon high suction, we have the school of thought which has concentrated upon the development of a constant suction instrument depending upon a moving part in order to ensure automaticity in action.

Moving parts controlling the degree of suction usually have a spring-actuated or spring-balanced air valve working against a difference of pressure between the inside and

the outside of the instrument, and as an alternative the weight of the part itself may be relied upon alone.

The Brewer carburettor is a combination of both systems, the suction being controlled both by the weight of the moving part and by the action of a spring whose effect can be adjusted at will. By this means the depression can be set so as to suit any particular engine.

The floating valve type of instrument has come very much to the fore during recent years, and it depends for its correct and satisfactory working, to a very great extent, upon accuracy of manufacture, particularly with regard to the dashpot and the valve stem.

Many of these instruments have given unsatisfactory results owing to the dashpot action not being perfect, and the immediate effect of any inaccuracy is that the floating element flutters to such an extent that the instrument absolutely refuses to work.

A fluttering air valve is chiefly objectionable on account of the noise it occasions, and for this reason American manufacturers frequently fit a leather-seated valve. When the valve is a separate entity, and in no way directly operates the jet, fluttering at once causes change in the composition of the explosive mixture.

On the other hand, where the air valve controls the jet orifice, the effect upon the mixture is not seriously marked, and it may have the effect of agitating the mixture, and improving its blending. For example, in one type of carburettor any fluttering of the valve causes rapid movements of the needle in the jet orifice, and assists in the breaking up of the fuel spray. No bad effect upon the pulling of the engine can be traced to valve fluttering with this instrument.

An instrument of this type, in which the action of gravity comes into play, has the following characteristics :—

(*a*) The inertia of the moving part due to the necessary weight which must be put into it, particularly with the larger sizes of instrument.

(*b*) The effect of this inertia upon the working of the instrument as the car passes along rough or bumpy roads.

(*c*) The liability to leakage of the air, or the effect of air leakage through the joints, which will naturally alter the depression within the mixing chamber for which the instrument has been calculated out.

(*d*) The leakage of fuel at the stem of the moving part when it is also assisting the dashpot action.

As an instance of the effect of an automatic moving part upon the depression in the mixing chamber of a certain instrument, the following observed values will be of interest:—

Weight of moving part = 1.5 lbs.
Net area of part upon which suction acts = 4.1 sq. in.
Calculated depression = 0.365 lb. = 9.5 in. water-head.
Engine, four cylinders, $3\frac{9}{16}$ in. × $4\frac{3}{4}$ in.

TABLE XLVI.

Engine Revs. per Min.	B.H.P. Developed.	Vacuum, Inches of Water.	Lift of Part in mms.
500	8.25	11.0	2.3
1,000	19.5	9.5	4
1,200	23.4	10.0	5
1,400	25.9	10.3	6
1,600	27.2	10.75	6.5
1,800	23.8	11.0	7.5

It will thus be seen that the moving valve regulates the depression with very fair accuracy, at any rate sufficient for all practical purposes.

Taking, therefore, the most usually adopted moving part in American practice, viz., the air valve, we will consider the difficulties in connection with a device of this nature, when one attempts to carry out a theoretically perfect carburation by means of this adjunct.

In the first place there is the inertia of the valve itself

to be considered, and secondly there is the spring error, which is of necessity a feature of all spring-actuated devices, where it is practically impossible to obtain springs of the same nature which can be relied upon throughout their active life.

Springs which are used in connection with air valves are, as a rule, misused, and the more accessible they become the more are they liable to misuse in the hands of the driver or the owner of the car. Furthermore, it is practically impossible on the road to give an accurate adjustment of any spring-actuated device of this sort, although, where the cost of fuel is immaterial, a sufficiently satisfactory result can be, and is, obtained in ordinary practice. There is, however, a certain period in the working of an instrument, viz., when the extra air valve begins to lift, where carburation is bound to be upset momentarily, due to the very great difference of prevailing conditions when the said valve operates or not, the effect of its lifting being a reduction in the vacuum within the mixing chamber.

In order to reduce the variation of vacuum at such a time to its minimum amount, two springs of different strength are sometimes employed, the lighter one coming into operation at the initial stages of the valve movement, its resistance being supplemented by that of a stronger spring as the valve lifts from its seat a further amount when the suction of the engine becomes greater.

The author, in designing his carburettor, has obtained a somewhat similar effect to the two-spring arrangement by utilising the weight of the moving valve to overcome the initial or low suction, so that the spring action is in reality operative over a short portion only of the valve's lift. Furthermore, on account of the design of the fuel orifice giving at all working suctions a flow of fuel proportional to the square root of the depression, any spring error is negligible for ordinary purposes.

In such a device the valve movement, to give full open-

ing, should be small, so as to still further eliminate errors due to variations in the shape of the air orifice.

Whilst considering moving parts whose effect is upon the constituents of the explosive mixture, the modulating pin must not be overlooked. As this important detail has been dealt with in previous chapters, we will only briefly refer to it here.

Such a part, subject to frequent changes of position relatively to the orifice in which it works, should be so designed that it does not suffer from wear, and it, therefore, should not be allowed to hang against the side of the fuel orifice.

This pin, together with the air valve, can be controlled by the same dashpot, and this may take several forms in actual practice.

At one time mercury was adopted as a suitable medium for damping out vibrations or oscillations of the moving parts, but this substance is expensive and heavy, and is liable to oxidise and cause trouble.

Nowadays pistons, either working in an air cylinder with a restricted orifice communicating with the atmosphere are used, or pistons in a fuel chamber. Wherever we have a piston of the ordinary sliding type, accuracy of fit is a *sine qua non*—if the fit is bad the piston is useless as a dashpot, if it is tight it restricts the movement of the parts.

A dashpot is primarily a device for damping out oscillations with as little friction as possible ; and where, as in the Scott-Robinson carburettor, a large piston is employed, a very small hole is drilled in the dashpot cover or piston so as to restrict the air flow into or out of the cylinder as the piston commences to descend or otherwise.

In this case tightness of the piston is obtained by a series of hydraulic grooves round the circumference of the piston, and the friction is small, as the amount of air passing through the hole is small.

The Stewart precision carburettor relies for its dashpot action upon a prolongation of the air valve stem which

works in a containing cylinder in communication with the fuel in the float chamber. The communicating hole is small, so that as long as the fuel does not creep up the stem it is forced backwards and forwards between the float chamber and the dashpot cylinder as the valve rises and falls.

The Polyrhoe dashpot is of the large air cylinder type, and in this case the operating spring is contained in the dashpot; and on account of the size of the spring this dashpot is of somewhat large dimensions.

Linked up with the question of dashpots and their need is that of inertia.

We will repeat the definition of the word inertia, so that it will not be necessary to refer to another chapter.

Inertia is that property of a body by virtue of which it tends to continue in a state of rest or motion in which it may be placed, until acted upon by some force.

Thus we see that a free moving air valve is subjected to continual forces of varying magnitude and periodicity on account of engine suction. The force acting is the atmospheric pressure tending to raise the valve from its seat, and the inertia of the valve is a function of its mass. When once the valve has started lifting, its tendency is to continue so doing on account of the velocity in a vertical direction, imparted by the impressed force. The valve has attained a momentum $\frac{mv^2}{2}$ at the end of time t, and this momentum must be damped out. Were an engine working at a constant load and speed the whole time, the question of inertia would not come in; but as this is not the case, we will see what its effect is.

In the first place, where the valve has considerable mass, it is quite possible that the engine suction will increase above the normal before the valve rises from its seat and admits more air. Under these conditions the mixture will tend to become rich. For this reason a light moving part is desirable.

If the range of possible working is great, the valve may

attain considerable velocity in a very short period of time after it has commenced to lift, and as the momentum is dependent upon the square of the velocity, the possible range of working should be small. With a spring-controlled valve, the effect of the spring increases as its compression, so that the spring itself brings the valve to rest before it has attained a seriously high velocity.

The valve is accelerated from rest to a certain velocity $V = F \times t$, where V is the velocity, F = the acceleration, and t the time during which the acceleration acts.

When the throttle is quickly closed the valve still tends to remain in its position of lift, and is only returned to its seat by the action of gravity, supplemented or not by that of a spring. A spring, therefore, is useful as beforementioned on account of its displacement being proportional to the pressure exerted. This pressure at once assists in returning the valve against its inertia property.

There is another condition under which the inertia of a valve may be detrimental to good working, namely, when the car traverses a bumpy road. It is here where a dashpot action should be as perfect as possible for carburettors whose jets do not proportion correctly. Rapid vertical accelerations to the car tend to cause the air valve to flop up and down.

What is termed "pick up" has become an important feature of modern design, and in a carburettor fitted with a moving part, the inertia of that part has a very important bearing upon this quality.

If the weight of the part is great, there is a tendency to lag when the throttle is suddenly opened. This is a good feature, perhaps, for ordinary driving, as it allows the engine to attain its power gradually. There is a class of user, unfortunately, who expects the engine to jump away so soon as the throttle is opened, and for his benefit there should be no appreciable lag in the carburettor action.

In the first place, the engine revolutions must increase to a certain amount before the necessary suction is obtained ;

and secondly, that suction must be allowed to operate for an appreciable time before the valve commences to lift by overcoming its inertia.

Throttles.—There is one other moving part to which brief reference will be made before passing on, and that is the throttle.

Three outstanding shapes of throttle are found at the present time—the barrel or sleeve, the butterfly, and the valve. Taking these in turn, it is generally found that the barrel throttle is adopted on the "single lever control" instrument, where it commands the air supply as well as the vapour, as in the Claudel Hobson. This type of throttle forms an important integral part in the design of the carburettor, and its parts should be correctly shaped to enable the carburettor as a whole to function properly and give the correct degree of suction at the jet orifice.

A barrel throttle must be a proper working fit in the carburettor body, both as regards its circumferential surface and that of its ends and trunnions, otherwise air leakage will be set up. This type of throttle has large working areas of contact, which should be kept free from scoring, and particles of dirt should be excluded, as these will either cause the throttle to stick or will produce scoring of the surfaces.

Some barrel throttles are so arranged that they bring into operation two or more fuel jets in sequence, so that as they are rotated, specially shaped air ports allow the air to be drawn through the choke tubes surrounding the said jets. In other cases a barrel throttle is sometimes arranged so that at the end of its limit of working communication is made with the outside air, thus enabling a supplementary air supply to be drawn into the cylinders at periods of high engine speed. On the other hand, this communication with the air may be made by overrunning the closed position of the throttle, so that air alone can pass into the cylinders when descending a hill.

Some emphasis is given by certain designers to the necessity of giving a uniform progressive throttle opening as the actuating lever is operated, but the author attaches

no importance to this property. The reason is that foot control is now so universal that the driver instinctively depresses his pedal in accordance with the performance of his engine. It is, however, important that the first few degrees of lever movement do not cause the engine to race away, otherwise there may be some difficulty in making the slow running adjustment.

Sleeve throttles are generally similar in their arrangement and function to the barrel, excepting that the trunnions are dispensed with, and the movement is longitudinal instead of rotary. The necessity for tightness and the exclusion of dirt still remains.

The butterfly is the simplest form of throttle to make, and this, the original type, has entered upon a new lease of popularity with the introduction of the weight or suction operated carburettors. On the other hand, the butterfly is almost universally employed in American practice with all types of instruments, probably as this class of throttle is cheap and easy to make, and does not rapidly become deranged even under the worst conditions of dust and dirt.

The butterfly should be of substantial design, as it is essentially a means of holding up the suction of the engine and regulating the extent of the effect of this suction upon the mixing chamber of the carburettor. Furthermore, the trunnions upon which the butterfly works should be of ample dimensions, having a large bearing surface, so as to prevent air leakage and maintain the throttle in its correct position. A butterfly in its closed position should not be normal to the bore of the tube in which it works, on account of the turbulence which it sets up; preferably it should, when closed, be at a good inclination, so that small movements of the lever only are required to produce full throttle opening.

The trunnions can conveniently be made to work in detachable bearings, screwed into the body of the instrument, to provide ready means of renewal, and the bearing remote from the actuating lever is better formed with a closed end, so that air leakage is positively prevented.

A typical butterfly throttle of advanced design is shown in Fig. 22.

The valve throttle is employed in some cases on the score of its ease of correct fitting, and owing to the fact that it can readily be seated and kept tight. Such a throttle is similar to the ordinary mushroom valves, fitted to a poppet valve engine; but one point must be borne in mind in considering the application of such a throttle in particular, and that is the deflection of the vapour stream.

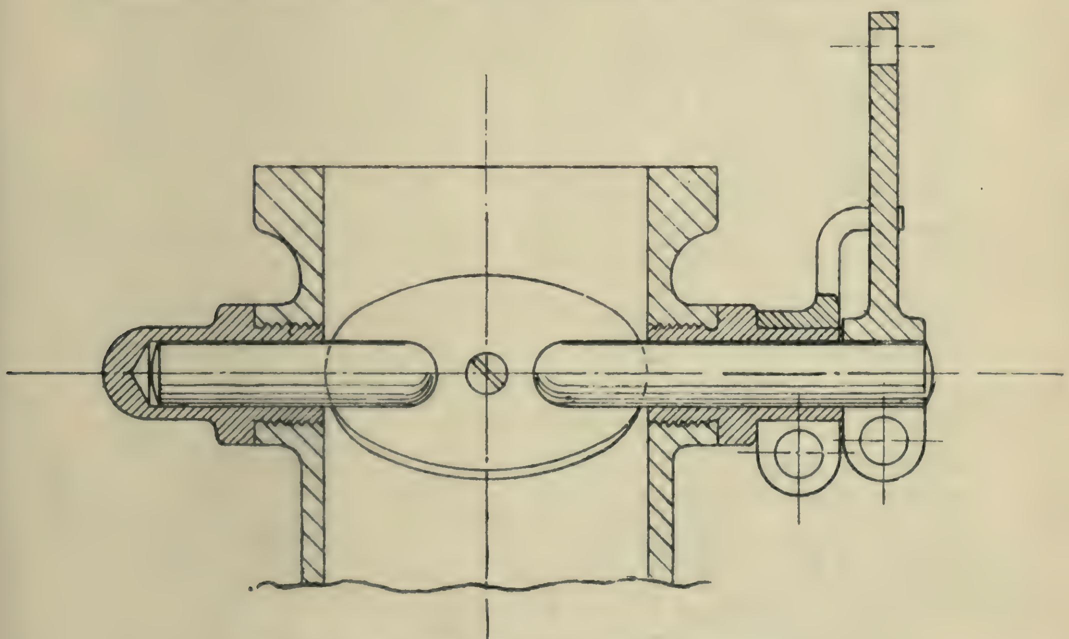

Fig. 22.—Butterfly Throttle of Advanced Design.

As previously pointed out, obstructions are to be avoided as much as possible, so any type of throttle should, when full open, at any rate, cause as little direct obstruction, particularly by normal surfaces. The valve can, of course, be suitably designed with this object in view, but care is required.

A valve throttle should not suffer from wear, and its actuating mechanism can be so arranged that there is no direct communication between the mixing chamber and the external atmosphere, even if any parts do wear. This is a point in its favour.

CHAPTER X

FLOAT CHAMBERS

EVERY modern carburettor is fitted with a float chamber, the duty of which is to maintain a constant level of fuel in the instrument itself, and this device has been almost universally adopted ever since the celebrated Maybach patents were fought out in the law courts.

It is quite possible, however, to eliminate the float chamber, and several attempts in this direction have been made with more or less success, but as a commercial proposition many difficulties occur when the elimination exists. In the first place, the variation of fuel head in the tank is difficult to compensate for unless a sudsidiary tank is provided, fitted with some means of regulating the flow of fuel to this subsidiary tank as the jet allows fuel in measured quantities to pass through to the engine. The ordinary float chamber can be operated in many ways, and several examples are shown in the following figures.

The first important point to bear in mind in designing a float chamber arrangement is, that the chamber itself should have sufficient capacity in order to prevent the engine stopping under abnormal conditions, or when the fuel is not flowing regularly to the float chamber. Secondly, the area through the needle valve which supplies the float chamber must be of sufficient size to pass the necessary amount of fuel, even when the tank is almost empty and the fuel head is low.

In several designs of carburettors, difficulties have been experienced in getting the fuel into the float chamber, due to the needle valve being too small, and it must be borne

in mind that the area through this valve should be considerably larger than the area of the jet orifice. In cases where the fuel needle is situated above the float, the fuel, on issuing from the needle valve, strikes on the top of the float. When the fuel issues at high velocity the pressure due to the velocity of the fuel acts upon the float—the issuing stream striking on the top of the float will tend to prevent it rising, and thus will, in some instances, cause the carburettor float chamber to flood. In cases where the float is supported, as in common American practice, from a hinge at one side, the effect of the issuing stream upon the float is very small, as the moment of the pressure about the fulcrum from which the float swings is a very small one, and therefore its effect upon the float is negligible.

It is probably unnecessary to point out that the action of a carburettor float is similar to that taking place in the ordinary domestic water cistern fitted with a ball valve, and the float performs the same function as the ball itself, through the medium of levers, or by direct connection, and closes the fuel inlet valve when the level is at a predetermined height.

In the working of a carburettor it may happen that, on account of high engine suction, the level of the fuel in the float chamber does not stand at the same height as the rest level, and it has been thought in the past that the deviation from the true level had a serious effect upon the operation of a carburettor jet.

The author considers that this is a fallacy.

If one comes to consider the small deviation that is possible in the float chamber as related to the total depression, or difference of pressure, between that of the mixing chamber and the float chamber, it will be seen that the proportionate discrepancy in the level bears a very small relation to the total depression. For example, it may occur that the depression in the mixing chamber is of the order of from 10 in. to 15 in. of water-head, whilst the error in depression in the float chamber will

only amount to a fraction of an inch, which is quite negligible. There is another point upon which the author takes the opportunity of expressing an opinion, and that is with regard to the necessity of fitting an air vent hole in the top of the float chamber. Owing to the difficulty experienced in some cases in getting sufficient fuel to pass through the needle valve of the float chamber, the author considers that it is advisable not to use a vent hole in this chamber, and to allow the suction upon the jet to facilitate or accelerate the flow of fuel through the float chamber needle valve. When there is no vent hole in the float chamber, this suction of course comes into operation, whereas when a vent hole is employed, the only difference of pressure which is effective is the difference of pressure due to the head of the fuel in the tank, above the needle valve of the float chamber.

The author has found no difficulties in practice on account of the elimination of a vent hole, but in some cases flooding may result.

Now, with reference to the float itself, some authorities consider that it should be a fairly close fit in the float chamber, as the proximity of its walls to those of the float chamber would assist in locating the float, and prevent it moving about. Messrs Gillett and Lehmann carried this idea still further in shaping their float as a double cone, with the object, in the first place, of retaining a large bulk of petrol in the float chamber ; and secondly, to guide the float itself, as the large ends of the double coned float were of almost the same diameter as the float chamber, thus steadying the float within the chamber. Such a shape of float is also very sensible to movement, but is largely self-damping, on account of the resistance given by the conoidal surfaces to movement in a vertical direction. This type of float, in actual practice, was arranged to rest upon a pair of small balance levers in the ordinary way, with a central weighted fuel needle having its seating downwards.

With further reference to the shape of the float, it is important to bear in mind that in cases of hollow brass floats, which are so frequently adopted in ordinary practice, there may be difficulties arising due to the difference between the internal and external pressure to which the float is subjected, and for this reason the ends of the float should not be flat, but should certainly be dished or corrugated to allow for slight expansions and contractions of the air enclosed within the float. Unless these precautions are taken, leakage is very liable to set up on account of the working at the soldered joints.

In the construction of floats of this type it is well to eliminate as far as possible all joints, and a suitable float can be made from two pressings soldered together with one circumferential seam. These pressings or stampings must naturally have more seams than one, in cases where the needle passes through the centre of the float, or when a passage is provided for the jet, as in the concentric type of instrument. In any case, however, care should be taken in the design so that the number of soldered joints can be reduced to a minimum.

Modern practice, particularly in America, is quite in favour of the cork float, but it is advisable that when such a float is used, it be built up of a large number of layers of cork to prevent warping. Six layers form a convenient number, and in many instances the cork is treated with shellac, and baked at least twice before being fitted into the float chamber. This is done to prevent the cork becoming sodden in use.

There are many methods by which the float actuates the valve, and it may be attached directly thereto, so that when the float lifts, the valve is drawn up on to a seat. On the other hand, the float may only have a small amount of buoyancy, sufficient to take its own weight from a needle which is pressed, or drawn up, on to its seat by means of a spring (Fig. 24).

The converse of such an arrangement is the downward

seated needle, where the needle seat is at the bottom of the float chamber, and the needle is of sufficient weight to seat itself when any counteracting pressure is relieved from it. In such a case the float operates through the medium of toggle levers, and as the float rests upon these toggle levers they in turn raise the needle from its seat (Fig. 25). Similar arrangements to those described are in some instances fitted to the top of the float chamber, but it is immaterial, generally, where these fittings are placed, so long as sufficient pressure is allowed to act upon the needle valve in order to keep it petrol tight (Fig. 26).

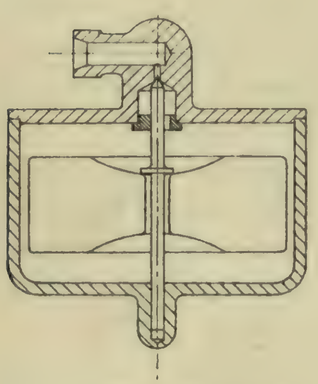

FIG. 23.

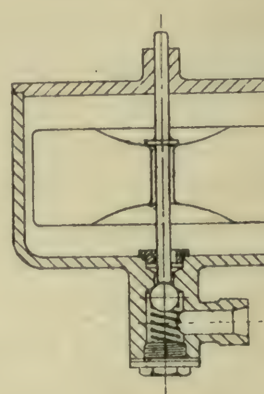

FIG. 24.

In passing it may be pointed out that unless a conical seated needle is true, and is prevented from rattling or shaking, it is often liable to leak. In practice it is somewhat difficult to get the needle tight, unless grinding is resorted to, due to inaccuracies in drilling the various holes through which the needle passes in a perfectly true line. For this reason a spherical seat is preferable, as it allows a slight movement to take place without causing the needle to leak.

In the Brewer carburettor the conical needle has been abandoned in favour of the spherical seated needle, which has been found to work very satisfactorily under all ordinary conditions (Fig. 31, p. 163).

There is one other point which should receive attention before leaving the subject of the float chamber, and that is the position of the float chamber relatively to the mixing chamber.

It has been the general practice in the past to make the float chamber on a different centre line to the mixing chamber, and the two situated side by side. When the carburettor is placed in position on the car, the float chamber may be either at one side of the mixing chamber, or in front of it, or behind it. There is a certain amount of importance attached to the position of a float chamber

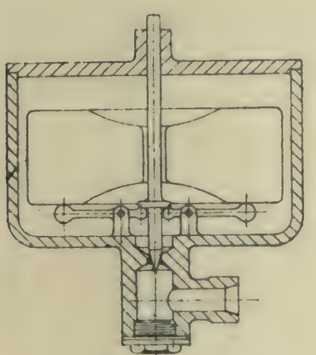

FIG. 25.

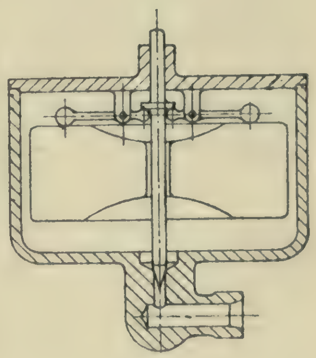

FIG. 26.

which is not on the same centre line as the jet, as it will be seen that, as the car ascends a hill, when the float chamber is in front of the mixing chamber, the tendency is for the jet to receive rather more than its normal supply of fuel, which is convenient. Conversely, on descending a hill, the inclination of the car retards the flow of fuel by reason of the difference of the two levels. When, however, the float chamber is placed to the rear of the mixing chamber, the reverse takes place, which is a scarcely desirable feature.*

Probably the best arrangement is the concentric system, where the float chamber is below, and the float itself surrounds the jet, as in this case the relations between

* The reader is referred to remarks on p. 117, last paragraph.

the level of fuel in the float chamber and in the jet orifice are always the same. Furthermore, it makes a very convenient manufacturing proposition, and the carburettor generally is of much smaller dimensions than when a separate float chamber is employed.

The concentric arrangement reduces to a minimum the length of the fuel passage to the jet, and consequently inertia effects are reduced in the fuel stream.

A concentric carburettor lends itself to universal fitting, as by a simple means the air and fuel openings can be set in any desired position relatively to one another.

An important point arises in the attachment of the fuel pipe to the float chamber, and it should be such that the bulk of the vital parts of the carburettor, such as the float and needle valve, also the jet, can be removed without disconnecting the fuel union.

CHAPTER XI

PETROL SUBSTITUTES

OWING to the high price of petroleum spirit, and the tendency of this price to increase, a considerable outcry has arisen and attention been turned to fuels other than those usually adopted. It is outside the sphere of this book to deal fully with the question of possible motor fuels, but this opportunity is taken to remind the reader that there are no great or special difficulties connected with the use of alternative fuels. The wisdom of doing so, however, is another matter, and it is evident that so long as the source of the substitute is the same as that of petroleum spirit, and so long as the same groups of financiers control the substitute as the present fuel, difficulty and doubt will always arise as to the practicability of adopting that substitute with any financial saving.

However, if a greater proportion of the crude can be used for motor vehicles than at present, it would be logical to suppose that a reduction in price of the all-round fuel should ensue. Thus, supposing that instead of, say, 15 per cent. of the crude, as at present, we could use 30 per cent. by suitable treatment, the average price would be the mean between that of the lighter distillate and that of the heavier, plus the cost of treatment.

The treatment of hydrocarbon liquid fuels is no new thing, and generally consists in precipitation of the unsaturated hydrocarbons contained in the fuel by means of certain acids.

Cracking is resorted to in order to increase the yield of the lighter hydrocarbons from the crude, and by this means

volatile spirit can be produced from the heavier hydrocarbons. In this way it is possible to break down petroleum of a high boiling point to an oil of a lower boiling point and an increased yield of the lighter products is obtained.

Mr Horatio Ballantyne, the well-known chemist, states that if one proposed to start with an oil having the approximate formula $C_{13}H_{28}$, and to reduce it to, say, heptane, having the formula C_7H_{16}, it would be necessary to increase the proportion of hydrogen relatively to the carbon. However, no practical means are known to chemistry whereby this can be done, but by a simple cracking of the oil, volatile mixtures of paraffins, unsaturated hydrocarbons such as olefines and benzene and its homologues, might be arrived at.

In the production of light oils, such as petrol, it is difficult to conduct the breaking down of the heavier oils without producing carbon and large proportions of permanent gases, such as methane, CH_4, and hydrogen. The most likely method of cracking oil for the purpose of obtaining spirit without such risk would therefore appear to be by means of distillation under high pressure, so that the temperature can thereby be more carefully regulated.

Liquid fuel has from time to time been treated by the addition of picric acid and by various gases, but such practices are not to be recommended. In the first place, petroleum spirit will not contain any appreciable proportion of the former in solution, and with the latter the involuntary liberation of the gases causes trouble in the jet.

The weight of gases which is soluble in petrol is very small, and even in the case of acetylene only 0.15 per cent. by weight can be contained in solution.

Mr Ballantyne states that "when the carburation is such as to give a mixture of petrol and air in about the theoretical proportions, acetylene does not act beneficially, and the greater sensitiveness of the acetylene tends to

cause pre-ignition. In the case of petroleum products of less volatility than petrol, treatment with gases leads to no improvement."

With reference to mixtures of liquid fuels, such as paraffin, petroleum spirit, benzol, and alcohol, experiments have been carried out for many years by the author and others, and it is notable how the admixture of certain proportions of a volatile liquid with one which is less volatile enables the latter fuel to be burnt in the engine cylinders. The obvious reason for this fact is that when a sufficient disintegration of the fuel takes place at the carburettor jet, and provided that the velocity of the fuel through the carburettor and inlet pipe is maintained, the heavier particles of the composite fuel are held in suspension in the incoming charge and ignited in their liquid state in the cylinders.

When using such a fuel it is therefore obvious that the remarks in a previous chapter on capacious inlet manifolds do not hold good, for the temperature of the walls due to the proximity of the circulating water is never sufficiently high to evaporate any precipitated particles of fuel.

Care must also be exercised, in consideration of the capacious manifold argument, that the *nature* of the fuel is taken into account, for the heavier fractions of ordinary motor spirit only boil between 130° C. and 150° C., whereas the temperature of the manifold is never as high as 100° C. A mixed fuel can be detected by analysis.

Alcohol, for instance, is soluble in water, and can be separated by the addition of water to the mixed fuel. The alcohol will dissolve, and the proportion of the remaining fuel which floats on the top can be measured.

Mr Ballantyne gives a nitration test for the detection of benzene (benzol).

To 25 c.c. of nitric acid (sp. gr. 1.42) add carefully 25 c.c. of concentrated sulphuric acid, and cool the mixture to about 20° C. to 30° C.

Add 25 c.c. of the sample gradually, and with constant

agitation, taking care not to allow the temperature to exceed 50° C.

If benzene is present, the odour of nitro-benzene will be noted.

Keep the mixture at a temperature of about 60° C. for half an hour with frequent agitation ; pour the whole into a separating funnel.

The waste acids can now be tapped off from below the upper layer of petrol and nitro-benzene. Now add nitric acid of sp. gr. 1.5, sufficient in quantity to dissolve the nitro-benzene, and the solution can be tapped off from below the layer of petrol, which can now be measured.

The acid solution should be poured into, and well agitated with, five or six times its volume of water, and the nitro-benzene is thus thrown out of solution, and can be measured.

The observed volume of nitro-benzene, multiplied by 0.85, gives the correct volume of benzene.

The author has conducted a number of tests with mixed fuels specially treated in order to determine the best proportions of the various constituents for all-round work.

In carrying out these tests it was primarily set down as a *sine qua non* that an ordinary standard carburettor should be used, without making adjustments of any sort, and that the car and engine should be changed over from one fuel to another as desired.

The principal points noted were :—

Ease of starting.
Acceleration.
Power on inclines or falling off in speed.
Maximum speed obtainable on the track.
Consumption.
Slow running.
Behaviour under rapid changes of throttle opening.

TABLE XLVII.—MIXED FUEL TESTS AT BROOKLANDS.

Claudel Carburettor.

Fuel.	Specific Gravity at 57° F.	Speed, M.P.H.	Consumption—Pints per Hour.	Miles per Gallon.	B.H.P. at Road Wheels.	I.H.P.	Pints of Fuel. B.H.P. Hour.	Pints of Fuel. I.H.P. Hour.	Mean Acceleration to 30 Miles per Hour—Feet per Sec. per Sec.
No. 2 - -	0.751	30.6	12	20.15	10.5	13.5	1.14	0.89	0.465
No. 2 - -	0.751	43.7	21.4	17.65	24.5	32.7	0.875	0.655	...
No. 3 - -	0.758	30	11.2	20.7	10.5	13.5	1.065	0.83	0.340
No. 4 - -	0.763	30	10.9	22.0	10.5	13.5	1.04	0.81	0.677
No. 5 - -	0.767	27.6	9.83	22.4	10 5	13.5	0.936	0.73	0.44
No. 6 - -	0.762	28.8	10.5	22.0	10.5	13.5	1.00	0.78	0.42
No. 8 - -	0.766	29.5	11.0	21.5	10.5	13.5	1.05	0.815	0.465
No. 8 - -	0.766	47	22.3	16.9	29.6	38.0	0.750	0.587	...
No. 9 - -	0.764	29.3	10.6	22.0	10.5	13.5	1.01	0.785	0.465
No 14- -	...	31.1	12.0	20.6	11.6	14.9	1.03	0.805	0.98
No. 14- -	...	45.7	23.2	15.7	22.4	25.6	1.03	0.95	...
Shell red -	0.715	29.3	10.5	22.0	10.5	13.5	1.00	0.78	0.98
Shell red -	0.715	48.3	23.2	16.3	30.5	39.1	0.76	0.593	...
Brewer Carburettor.									
Shell crown -	0.750	31.5	11.4	22.0	11.0	14.1	1.01	0.81	0.88
Shell crown -	0.750	40.6	17.7	18.4	25.6	33.8	0.69	0.525	...
Benzol -	0.880	30.0	10.0	24.0	10.5	13.5	0.95	0.74	0.98
Benzol -	0.880	40.0	14.1	22.5	25.0	33.0	0.56	0.425	...

The various fuels were tested in the author's car, which is conveniently adapted for such work. Elimination of the undesirables has only taken place up to the time of writing, but as these varied in only minor degrees with regard to their constituents from the best fuel, the different behaviours will be of interest. The two carburettors used were, first, a Claudel Hobson of 26 mm. diameter, and a Brewer carburettor of nominal 1 in., which was, however, never fully opened up.

The remainder of the tests with the fuels in this carburettor were carried out on the road, so that the results are not comparable.

The car loaded weighed 1.5 tons, and had a rolling resistance of 130 lbs. on the track at 30 miles per hour, and 210 lbs. at 43.7 miles per hour, and 236 lbs. at 47 miles per hour.

A wide wind-screen was in use during these tests, but the weather was calm each day.

Benzol.—The carburation of benzol requires no special apparatus, and is attended with no difficulties. This fuel can be used with any good carburettor without alteration, as has been proved for years past. The author conducted a number of experiments in the years 1905-6 with benzol, which then cost about eightpence per gallon at the gas works, and he showed that the saving which could be effected was proportional to the relative prices of benzol and petrol, plus about 12 to 20 per cent. in favour of benzol. This is no doubt due to the greater specific gravity of the benzol, *i.e.*, about 0.880 to 0.885 as compared with petrol at 0.715, and therefore to the greater weight of benzol in one gallon, the standard unit of sale retail.

Benzol, as we all know, is a distillate of coal tar, whose formula is C_6H_6, and contains about 163,680 B.Th.U. per gallon, as compared with about 157,000 B.Th.U. in the case of petrol, or taken by weight about 20,000 B.Th.U. for petrol per pound.

The total evaporation or boiling point of crude benzol

is 145° C. or 293° F., and it has an explosive range of 2.7 to 6.3 per cent.

Crude benzol is not, however, suitable for motor car work, and it is, therefore, washed or purified for this purpose, chiefly in order to eliminate certain sulphur compounds which are contained in solution.

Pure benzol boils at about 80° C. or 176° F., but commercial 90 per cent. benzol is more usually met with, and 90 per cent. of this hydrocarbon liquid evaporates in a retort at 100° C. 90 per cent. benzol consists of the following combinations, whose proportions vary between 70 to 75 per cent. benzene, 24 to 29 per cent. toluene, and 17 per cent. xylene, but in some cases the benzene may be as high as 80 per cent., and the toluene as low as 14 per cent.

The presence of toluene is desirable on account of its lower freezing point, as pure benzol will freeze at a temperature of 42° F., whereas, when a considerable proportion of toluene is in the product, the freezing point drops to 5° F.

The production of crude benzol at the gasworks from 1 ton of coal distilled is at present about 2½ galls., and its bulk is reduced by 25 per cent. in rendering it suitable for motor car purposes, this yield depending upon the amount of gas distilled per ton of coal, and may be as high as 9 galls. per ton of coal when 7,000 cub. ft. of gas only are distilled.

The sulphur compounds in benzol are washed out to a great extent by means of sulphuric acid, as these amount to about 150 grains per gallon, and are easily discernible by their smell. The process of washing and refining costs a penny to twopence per gallon. In 90 per cent. benzol there remains from 75 to 90 grains per gallon of carbon, bisulphide, and other compounds.

The difficulty about benzol, from the motorist's point of view, is that he cannot easily obtain it, and furthermore, is not likely to do so in any quantity for some time on account of the large export trade, particularly with France. The absence of duty on benzol into France, and the prefer-

ential local *octroi* into Paris make benzol an attractive fuel in the French capital, so that the refiners of benzol in England find a ready and profitable market in that country.

The fuel question is too deep a one to go into fully here, and is more dependent upon finance than upon engineering possibilities; but suffice it to say that, were benzol procurable in reasonable quantities, it could form a serious rival to petrol. As far as we can see at present, there is, however, no reasonable hope that the yield of benzol from gasworks could ease the fuel situation appreciably.

Benzol is also produced in the manufacture of coke for metallurgical purposes, and at the present time 10 to 12 million gallons are produced per annum in England in this way, and the yield may be as high as 14 galls. per ton of coal carbonised.

If modern recovery plants were utilised in every works where the manufacture of coke is carried on, it would be possible to increase this yield to 30 million gallons of benzol per annum. The price of benzol is in a great measure governed by the price of petrol, and at the time of writing is about one shilling per gallon in bulk at the works; a few years ago it was half this price.

As far as the physical properties of benzol are concerned, M. Edmund Ledoux gives the calorific value of benzol as 8,844 major calories per litre, as against 7,910 for petrol, showing a favour of 12 per cent. for benzol.

The heat required to vaporise a quantity of liquid of each, containing 1,000 calories of heat, is—

$$\left.\begin{array}{l}\text{Benzol} = 12.9 \text{ calories} = 1.29 \text{ per cent.}\\ \text{Petrol} = 14.1 \quad ,, \quad = 1.41 \quad ,,\end{array}\right\}\text{of the total heat of combustion.}$$

From the above figures 89.3 volumes of benzol contain the same quantity of heat as 100 volumes of petrol.

It will be seen that a smaller volume of benzol is required than that of petrol to carburate a given quantity

of air, but it is found that the viscosity of benzol is greater than that of petrol, almost in the exact ratio of the required reduction of volume of fuel shown by the above figures.

TABLE XLVIII.—TIMES TAKEN FOR 2 OZ. OF LIQUID FUEL AT 55° F. TO FLOW THROUGH AN ORIFICE 0.95 MM. DIAMETER.

Fuel.	Head over Orifice corrected for equal pressures in mms.		
	30	40	60
	sec.	sec.	sec.
"Anglo 0.760"	77	70	50
Benzol	116	106	80

TABLE XLIX.—TIMES TAKEN FOR 2 OZ. OF LIQUID FUEL AT 55° F. TO FLOW THROUGH AN ORIFICE 1.2 MM. DIAMETER.

Fuel.	Specific Gravity.	Equivalent Head for Petrol = 120 mm. Benzol = 99 mm.	Head for Petrol = 150 mm. Benzol = 124 mm.	Head for Petrol = 180 mm. Benzol = 148 mm.
		sec.	sec.	sec.
"Anglo 0.760"	0.730	62	35	30
Benzol	0.885	75	37	33

TABLE L.—QUANTITIES OF BENZOL (SP. GR. 0.875) FLOWING THROUGH ORIFICES IN GALLONS PER HOUR. TEMPERATURE, 66° F.

Diameter of Orifice in mm.	Fuel Head = 120 mm. Equivalent Water-Head = 105 mm.	150 131	180 157
	Gal.	Gal.	Gal.
1.0	0.775	0.94	1.07
1.2	1.21	1.36	1.55
1.4	1.83	2.06	2.25

TABLE LI.—QUANTITIES OF BENZOL (SP. GR. 0.875) FLOWING THROUGH ORIFICES IN LITRES PER HOUR. TEMPERATURE, 66° F.

Diameter of Orifice in mm.	Fuel Head = 120 mm. Equivalent Water-Head = 105 mm.	150 131	180 157
	Litres.	Litres.	Litres.
1.0	3.52	4.27	4.86
1.2	5.5	6.18	7.04
1.4	8.32	9.31	10.22

The reason why two figures are given for the head in each instance in the above table is that in a carburating system all readings are taken in water-head, the depression at the jet orifice is reckoned in inches or mms. water-head, and this reckoning must not be confused with the theory of hydraulics, where the acting head of the liquid is the basis.

Paraffin.—This distillate from the petroleum series has probably been used to a greater extent than any other, and principally for domestic purposes and for use in internal combustion engines. As soon as the gas engine became a commercial possibility attention was turned to the use of oil, and the oil engine progressed simultaneously with the gas engine.

Carburation, in the broad sense of the word, covers any means of intermingling hydrocarbon with air in suitable proportions to form a combustible mixture, and the conversions of solid coal into gas is at the lower end of the series, which at its upper end consists in the evaporation at ordinary temperatures of a light benzene.

If one considers the question in this manner, it will be obvious that as one progresses along the whole series the various fuels to be treated require greater additions of heat in order to effect carburation as the particular fuel approaches the end of the scale of fuels which terminate with coal.

We will not consider here any fuel more difficult to carburate than paraffin, as from the automobile point of view, fuels with higher boiling points and more difficult of treatment are scarcely within the range of possibility at the moment.

The advent of the Diesel engine, followed by other types of engines in which the fuel is directly injected into the cylinders, has rather detracted from the lines of progress in systems of using paraffin, either in its liquid or gaseous form, and in this form admitted to the engine during the suction stroke. This latter has for more than twenty-five years been the method adopted for utilising oil in the cylinders of stationary internal combustion engines, and naturally during that time certain fixed methods have been employed for suitably dealing with such a fuel.

Two distinct systems exist for carburetting air by means of a liquid fuel whose boiling point is above 150° C., and these are as follows :—

1. As paraffin or kerosene without chemical change, either in an atomised, or partly atomised and partly vaporised state. 2. With chemical change such that the paraffin before entering the cylinder has been wholly or partly decomposed into the lighter hydrocarbons.

The first method was adopted in the early Priestman engine, and a spray producer of special form was fitted into the end of a cylinder in such a manner that the fuel was injected into a hot combustion chamber in the form of spray, and there more or less decomposed, at any rate sufficiently to form a combustible mixture. When such a method is attempted in connection with a modern automobile engine, and a spraying device is used to supply a number of cylinders, there is always the liability for the suspended particles of fuel to deposit as a liquid in the induction pipe unless the atomisation takes place in close proximity to the cylinders.

This deposition of liquid is naturally aggravated by any bends or obstructions to the passage of the fuel on its

way from the atomising device to the engine cylinders, and for this reason alone it is practically impossible to rely upon an external atomiser alone for the carburation of air by means of paraffin.

Under the second series we have a different state of affairs, and an attempt is here made to produce an oil gas such as is well known in the Manfield process. If we are using a fuel which evaporates completely between 150° and 300° C., and that fuel is submitted to a temperature at least equal to that of the boiling point of its heaviest fraction, we shall produce an oil gas which is more or less fixed.

When we have such a gas it does not so readily recondense into its liquid form, and it is, therefore, more easy to deal with, than a mere vapour produced by mechanical means.

However, in producing a gas from oil by means of a heat treatment, there is always the likelihood of forming carbon deposits in the vaporising chamber, particularly if the temperature is so high that the fuel cracks. We have previously seen that under certain circumstances trouble is likely to occur through the recondensation of vaporised liquid, and this trouble is cumulative, for if a missfire occurs through the condensation of a portion of an incoming charge, that part of the fuel which has entered the engine cylinder is likely to further condense and to spoil the following charge.

The presence of too much hydrocarbon, or too little when the mixture consists of paraffin vapour, is very much more important than when petrol vapour is employed; and whereas in the latter case ignition can take place between the limits of 1.2 per cent. of petrol vapour to air and 5.5 per cent. at ordinary temperature pressure, or between 1.84 and 0.4 times the correct amount of air, yet in the case of paraffin only about one half this latitude is possible.

For this reason it is imperative, when using paraffin,

that the proportions of fuel and air should be exactly measured.

Now, as the volume of vapour produced from a liquid is enormously greater than the volume of the liquid itself (*i.e.*, in the case of petrol it is 190 to 230 times as great), it is much easier to measure a volume of vapour than a volume of liquid. Furthermore, owing to the very small volumes of liquid which pass to the ordinary automobile engine, it is extremely difficult to measure these volumes with any great degree of accuracy. The author, therefore, contends that the most practical method of dealing with the question of paraffin carburation is first to convert the fuel into a fixed gas, using some form of measuring device which fairly proportions the amount of liquid fuel to the air passing to the engine, and to measure exactly and proportion the amount of fuel vapour to the total amount of air.

We have, in the internal combustion engine, at our disposal a certain amount of waste heat in the exhaust of the order of 40 per cent. of the total heat of the fuel, and by utilising the heat in a proper manner we can, without much cost, fix up an oil gas producer.

There has been in the past a great divergence of opinion as to what is the proper method of utilising heat in order to obtain satisfactory carburation, and at the present time, for automobile work, there only appears to be one system which really works well. This system consists in an arrangement of evaporating paraffin in the presence of a small quantity of air, and then either using the mixture at its original temperature, or still further raising its temperature and mixing it with such an amount of additional air as will produce an explosive mixture. A definite figure for the necessary quantity of air which should be mixed with the fuel during its first heating process is between 10 and 20 per cent. of the total air required. The evaporated fuel should be superheated before mixing with the main air supplied, with the following objects—(*a*) of producing

a fog of extremely fine texture, and (*b*) of producing a fixed gas. With regard to the necessity of the former, it only needs reference to a previous chapter, in which the author shows how the surface of liquid exposed to the air supplied is in proportion to the cube root of the decrease of the diameter of the individual particles or globules of liquid, and the second consideration, viz., that of producing a fixed gas, is very obvious when one considers the arguments in connection with the formation of the inlet pipe. Although this operation may be complete in the vaporiser, yet on mixing such a charge with extra air, when the gas is properly fixed, any paraffin condensed in this form has practically no wetting property, and differs from the coarser particles formed by spraying the fuel. The coarser particles may burn satisfactorily in a comparatively slow speed stationary engine, but when we come into high speed automobile work the time element is so short that it is absolutely essential that the particles of hydrocarbon should be as finely divided as possible, in order that the rate of propagation of the flame through the mixture shall be as rapid and complete as possible.

It is obviously important that the fuel particles should be broken up into their smallest possible dimensions, and that sufficient heat be added, so that when the additional air is mixed with the finely divided particles of fuel there should be no recondensation in the mixing valve or the inlet pipe.

The most interesting and practical system of which the author is aware at the present time is that devised by the G.C. Vaporiser, Ltd., and the author has recently carried out some trials with an apparatus of this type in which the results were most satisfactory.

It is necessary first to consider the question of temperature. Evaporation cannot be complete unless the temperature to which the fuel particles is exposed is at least 300° C., as the maximum boiling point of the heaviest fraction is 300° C. It is obviously impos-

sible to obtain complete evaporation unless this temperature is reached. In the G.C. arrangement a temperature 570° F of 300° C. or thereabout is aimed at, and in order that this temperature should be maintained throughout all conditions of working, the G.C. apparatus comprises a thermal storage of considerable capacity. The capacity of this thermal storage depends on the duties for which the apparatus is required. For instance, if a car is to be fitted for use in traffic or any considerable periods of light running, it is necessary to have a sufficient thermal storage capacity in order that the apparatus should not cool down too much in working. The thermal storage is obtained by means of the exhaust silencer, through which the gas is passed in a circuitous path, and the storage of heat is taken up by particles of metal having a considerable capacity for the storage of heat. The passages for the hot gas through this thermal storage apparatus are arranged in a similar manner to those which one generally finds in a Lancashire boiler, viz., the exhaust gas is passed through from one end to the other and returned outside the original flue, an annular space being interposed between the two passages for the vaporisation of the paraffin. By this arrangement, although at the entering end the greatest temperature is reached, at the remote end the temperature of the whole apparatus is about a mean of the maximum and minimum temperature of the exhaust. By the time the gases have returned along the outer casing their temperature is still further reduced, so that at the entering end, in addition to having the maximum temperature at the centre, we have the minimum temperature outside. One might consider that, to be on the safe side, it would be necessary to have the temperature somewhat higher than the maximum temperature of boiling of the heaviest particles in the fuel, but then difficulties occur due to a certain amount of slow combustion going on in the fuel itself when oxygen is allowed to reach it. The amount of

this combustion has not been definitely determined, but Professor Morgan's investigations show how, as the gas and air pass through a heated tube, the proportions of CO at various points in the tube vary, thus showing that combustion is taking place in a manner which has been described by Dr Bone in connection with the surface combustion of gases.

Professor Morgan heated his mixture to a temperature of 600° C. for his second series of experiments, and this temperature was found to be a critical temperature at which combustion took place in mixtures of paraffin vapour and air. It is therefore obvious that in any system of vaporising of paraffin, in order to avoid the combination of the carbon in the fuel with the oxygen in the air, a temperature of less than 600° C. must be worked at. Professor Morgan states that below this temperature these reactions are so slow as to be inappreciable under the conditions prevailing in the petrol engine, but above this temperature the reactions are rapid, giving rise to inflammation or a condition approaching thereto. He further points out that the ratio of air to fuel had no effect on this critical temperature. It would be difficult to state at this stage of our knowledge whether the speed of the passage of the gas through the heated tubes had much effect upon the result, and in Professor Morgan's test the speed of the gas was slow, and this, of course, is the case in the G.C. apparatus.

Reverting now to the G.C. vaporiser system, one point in particular is most interesting, and that is, that as the hot gas is led away from the vaporiser to the mixing valve no precipitation of liquid is apparent, and even though in the mixing valve the majority of the air is added to the vaporised fuel, and the temperature is reduced to practically that of the atmosphere, yet there is no apparent precipitation of liquid here. This is most important, as obviously the low temperature of the vapour entering the engine enables a greater weight of explosive mixture to be intro-

duced to the engine cylinders in unit time than is possible in any other system of paraffin vaporisation, where the explosive mixture is led to the engine at a very high temperature. This low temperature of the carburetted air is only possible on account of the more or less fixed nature of the vapour before it is admixed with the air in order to form a combustible mixture.

TABLE LII.—CONSUMPTION PER HORSE-POWER HOUR AVERAGE LOAD.

1. *Petrol Engine.* 2. *Diesel Engine.*

	Pint.	Pence per Pint.	Pence per H.P.	Pint.	Pence per Pint.	Pence per H.P.
Fuel -	0.70	0.75	0.52	0.60	0.30	0.18
Oil -	0.02	5.00	0.10	0.03	5.00	0.15
Fuel and lubricant per H.P., 0.62d.				Per H.P., 0.33d.		

3. *G.C. System.*

	Pint.	Pence per Pint.	Pence per H.P.
Fuel -	0.65	0.37	0.24
Oil -	0.018	5.00	0.09
Fuel and lubricant per H.P., 0.33d.			

THE MAINTENANCE EXPENSES (15 PER CENT.), DEPRECIATION (15 PER CENT.), INTEREST ON CAPITAL (5 PER CENT.) PER HORSE-POWER HOUR.

Number of Daily Service Hours.	8	12	16
1 and 3. Explosion engine	0.15	0.10	0.07 pence per H.P.
2. Diesel engine - -	0.43	0.29	c.22 ,, ,,

The previous arguments are not given in any way as adversely criticising the Diesel engine, either in principle or as a commercial proposition, but to stimulate others who are working on the problem of paraffin or oil as a fuel for internal combustion engines, and to show them that it is quite possible to obtain very satisfactory commercial results with other methods than those adopted for the Diesel engine. That there is an undoubted field for the use of paraffin for the internal combustion engine is undisputed, but at the same time one must carefully bear in mind there are particular cases to which the use of paraffin is applicable.

Other really successful paraffin systems include the Morris, in which a modulating pin device is employed for regulating the fuel supply, a small percentage of air is allowed to pass with the fuel through a vaporising tube and the remainder of the air is added at the mixing value. No thermal storage is provided.

The Standard has also undergone satisfactory trials and operates in a somewhat similar manner to the G.C.

CHAPTER XII

EXHAUST GAS ANALYSES

In 1907 Dr Dugald Clerk, who is probably the greatest authority on the internal combustion engine, read an important paper before the Institution of Automobile Engineers on the principles of carburetting as determined by exhaust gas analyses. He was thus the first to draw public attention to the importance of this subject of determining what was taking place in the cylinders of an internal combustion engine. Attention had already been drawn to the question of the importance of making an examination of the exhaust gases, at the time of the trials made by the Royal Automobile Club, in connection with carburation in the motor car engine of the time. Sufficient indication was not, however, previously given that examination of the exhaust gases was to be the determining factor in awarding marks in connection with these trials.

Entrants for the trials were under the impression that the emission of smoke only was to be adjudicated upon, and there was somewhat of a revelation when the Committee's report was published, as it was shown that an amount of carbonic oxide equal to at least 2 per cent., and generally more, was prevalent in the exhaust gases of the majority of the cars under consideration, and that this percentage showed how imperfect was the carburation at that time.

The modern conditions of high speed motors make it extremely difficult to design a carburettor which will function correctly throughout the prevailing ranges of load and speed, and it is by means of the analyses of the

exhaust gases that we are most easily able to determine what is taking place under various working conditions.

It must not be considered that by exhaust gas analysis *alone* can the true determination be made, and it is extremely difficult to obtain, in the first place, fair average samples of exhaust gases, on account of the possibilities of missfiring, when charges are liable to escape into the exhaust in an unburnt state, and thus mingle with the sample of gases to be analysed. Furthermore, there is the possibility of air leaking into the samples unless the sampling is very carefully carried out. This leakage of air is, in some instances, due to pulsations in the exhaust pipe causing a certain amount of back flow of air up the pipe, after a partial vacuum has been produced immediately after the ejection of a burnt charge. This mingling, of what one might term foreign substances, gives a false impression as to what is actually taking place in the engine cylinders, so that considerable caution must be exercised in comparing the analyses taken from the exhaust of various engines unless very great care is taken in the sampling process.

A common method of determining the degree of success of the regulation of a carburettor is to examine the flame coming from the exhaust valve port under the various changes of conditions, and a carburettor can be regulated to a certain extent by noting that the flame leaving the exhaust port is not a long, luminous one, but short, blue, and non-luminous. This blue flame is supposed to indicate fairly complete combustion within the cylinder; but the method of testing is very crude, and gives but little real knowledge of what the carburettor is doing throughout the whole range.

Referring now to the trials of the Royal Automobile Club, Dr Dugald Clerk points out that whilst four of the cars under examination discharged an exhaust containing under two per cent. of carbonic oxide, eight cars discharged more than this quantity. The samples were taken by discharging the exhaust into copper drums, each about

800 cub. in. capacity, two samples being taken from each car.

A method of making a complete investigation is as follows. Exhaust samples could be taken—

(*a*) When the car was standing on the level with the engine running as slowly as possible.

(*b*) With the car still standing, but the engine running at various rates of speed from 600 up to 1,000 revs. per min.

(*c*) With the car running on the level at about 18 to 20 miles an hour with the throttle only partially opened.

(*d*) With the car climbing a hill, the engine running so that it gives approximately its maximum output.

Let us first consider the method of taking the samples, and it will be evident from the foregoing remarks that it is most satisfactory to take off a sampling connection as near as possible to the exhaust valves, so that the effect of pulsations does not appear in the sampling apparatus. Furthermore, the samples should be taken over a considerable period, so that a fair average sample of what is occurring is collected in the sampling vessel. When the sample has been collected it can be examined by Mr Horatio Ballantyne's method, which is as follows:—

CO, CO_2, and O_2 are first determined by the usual gas volumetric method, a known volume of the gas, about 50 c.c., is treated in succession with (1) caustic potash solution (50 grms. KOH plus 100 grms. of water); (2) alkaline pyrogallol solution (5 grms. pyrogallol, 50 grms. KOH, and 100 c.c. of water); and (3) acid cuprous chloride solution (used and fresh respectively), followed by caustic potash solution. The proportions of CO_2, O_2, and CO respectively are thus ascertained. The total time taken to make a rough analysis of exhaust gas by this method is about 10 to 15 minutes, and the various gases

are absorbed by the various solutions, and the reduction in volume of the samples is read off.

The proportions of the various gases are usually given in percentages by volume to the total.

Ethylene, hydrogen, methane, and nitrogen remain to be determined, and the usual gas volumetric methods may be employed. In making a rough analysis, however, these are frequently all lumped together and put down as nitrogen, etc. Mr Ballantyne states that he has found that for nearly all practical purposes it is unnecessary to determine these constituents by direct analysis, and an important saving in time and trouble is thus effected. The results are arrived at as follows :—

The proportions of hydrogen and methane bear a definite relation to the proportion of CO, namely, the percentage of $CO \times 0.36 =$ the percentage of H, and the percentage of $CO \times 0.12 =$ the percentage of CH_4. These two gases are, therefore, determined by simple multiplication. The nitrogen is determined by the difference, as in ordinary analyses.

The following table shows an approximate analysis of three samples of exhaust gas :—

TABLE LIII.

		1	2	3
By analysis	CO	1.8	2.4	2.2
	CO_2	5.6	11.0	11.8
	O_2	10.6	2.2	0.6
By calculation	H	0.6	0.8	0.8
	CH_4	0.2	0.3	0.3
	N_2	81.2	83.3	84.3
		100.0	100.0	100.0

The calculated results obtained, as above described, may be regarded as correct within the limits of error of an analysis by gas volumetric methods.

Professor B. Hopkinson, of Cambridge University, about the year 1907, made a large number of experiments upon exhaust gas analyses, and his results were embodied in a paper read before the British Association in 1907. These experiments were made on a four-cylinder Daimler engine, with cylinders 3.56 in. diameter by 5.11 in. stroke, and the engine was run under full load at a constant speed of 750 revs. per min. The Hopkinson tests are particularly interesting in this respect—they show that the percentage of CO_2 mounts from 10.9 to 13.5 per cent. by volume, as the horse-power of the engine increases to its maximum, and at the same time the thermal efficiency of the engine increases up to that point. Above that point and onwards, as the percentage of CO_2 falls from 13.5 to 9.6, the brake load curve is practically flat, and is at its peak. During this period it is interesting to note that the percentage of O_2 varied from 0.2 to zero, and the percentage of CO, which was previously a zero quantity, increased from 0.7 to 6.25.

As the percentage of CO was allowed to increase up to 11.6, the brake load rapidly fell off. The whole of this time the thermal efficiency of the engine was dropping rapidly.

It will thus be seen that within considerably wide limits a rich mixture of fuel maintains the maximum horse-power at a practically constant value, whilst the thermal efficiency drops off as the mixture is enriched, and that the most economical point to run is when the CO_2 is 13.5 per cent. by volume, the O_2 is 0.2 per cent., and the CO is 0.7 per cent., dropping down to zero. At this time the thermal efficiency of the Daimler engine under consideration was 0.26, or 26 per cent.

Power is in some cases more important than thermal efficiency, and this can be obtained in many instances by using a rich mixture which is not completely consumed.

Table LIV.—Experiments of Prof. Bertram Hopkinson and Mr L. G. Morse on a Daimler Engine.

Petrol Consumption in lbs. per 1,000 revs.	0.181.	0.191.	0.197.	0.217.	0.250.	0.292.
Thermal efficiency	0.244	0.252	0.261	0.238	0.204	0.162
CO_2 measured -	10.9	12.8	13.5	10.6	9.6	6
O_2 ,, -	3.6	1.5	0.2	...	...	...
CO ,, -	...	...	0.7	5	6.25	11.6
H_2 ,, -	...	...	...	2.1	2.65	8.7
N_2 by difference -	84	84	84	81	80	73
Total O_2 calculated from N_2 -	22.4	22.4	22.4	21.5	21.3	19.4
H_2O calculated -	15.8	16.2	16.8	16.8	17.2	15.2

Professor Hopkinson's experiments are particularly valuable, showing that an engine adjusted for maximum thermal efficiency at full power discharges an exhaust which is free from any objection, but an engine so adjusted may also have an innocuous exhaust at lighter loads, but this by no means follows; it depends upon the nature and design of the carburettor. If, however, the carburettor is designed to function by some automatic air valve device, it does not always follow that this functioning will take place at the correct moment, and there may be positions in the carburettor curve where large percentages of carbonic oxide are discharged. It may occur, for example, that the speed of an engine may be kept perfectly constant, but the position of throttle opening, and consequently the carburated mixture passing through the carburettor in any unit time, may vary through wide limits owing to the variations of road resistance, and it is, therefore, obvious that neither engine speed alone nor throttle opening alone can in any way accurately govern the amount of fuel and air passing to the engine.

Now it is useful for us to make a comparison between the figures as given above with those obtained by Dr

Watson, and given in his paper on thermal and combustion efficiency, and we find that the most efficient all-round mixture was obtained by Dr Watson when the ratio of air to fuel by weight was from 15 or 16 to 1. At this time the thermal efficiency was 0.249, or practically 25 per cent., and the mean effective pressure in the cylinder varied from 81 lbs. per sq. in. to 84 lbs. per sq. in. gauge.

When the strength of the mixture was weakened, and the ratio of air to fuel by weight was increased to 18.7 to 1, the thermal efficiency dropped to 0.230, and the mean effective pressure to 65.4 lbs. per sq. in. As the mixture was still further weakened, and the ratio of air to fuel was 19.4 to 1, the mean effective pressure dropped further to 55.4 lbs. per sq. in., and the thermal efficiency to 0.196.

At the other end of the scale, however, when the mixture was strengthened, we find in Dr Watson's tests that, as the ratio of air to fuel was increased to 12.3 to 1, the mean effective pressure increased slightly to 85.7 lbs. per sq. in., with a dropping thermal efficiency to 0.208. As the mixture strength was still further increased to 11.7 to 1, the mean effective pressure dropped slightly to 83.6 lbs. per sq. in., and the thermal efficiency dropped to 0.173.

Naturally the exact points where these pressures rise and fall depends not only on the mixture's strength, but to a certain extent upon the engine compression, and also upon the design of the engine itself. The figures that are given are merely indications of what actually occurs in practice.

Dr Watson's deductions were to the effect that when free oxygen appeared in the exhaust there was no carbonic oxide, and with a weak mixture one naturally finds an excess of free oxygen, and rarely finds carbonic oxide.

Conclusions which can be drawn from an examination of exhaust gas analyses as to conditions of perfect combustion may be cited as follows :—

The most important point is that completed combustion by no means follows because there is an excess of oxygen.

For instance, a carburettor may be adjusted in such a way as to give a substantial excess of oxygen throughout its whole range, and yet carbonic oxide is not necessarily suppressed, nor is complete combustion obtained. One can see, from an examination of various tables of exhaust gases, that it does not follow by any means that the percentage of carbonic oxide bears any definite relation to the percentage of free oxygen, and in working out an exhaust gas analysis for the comparison of the merits of different engines or different adjustments, the total fuel consumed should be tested in any given experiment, and from the exhaust gas analysis there should be calculated the proportion of that fuel which is rejected without burning.

An estimate can be made from the exhaust gas analysis as to the amount of air taken into the engine. For example, if we know the quantity of fuel supplied per minute and the percentage of free oxygen in the exhaust, we can calculate the proportion that this free oxygen bears to the total amount required theoretically for complete combustion. If, for example, the free oxygen should be 1.35 per cent., this is equivalent to 6 per cent. of the total oxygen taken by the engine. Making allowances of two-thirds of this to consume unburnt hydrogen and carbon in the exhaust, the remainder, or 2 per cent., shows the excess of air theoretically required to burn the fuel. The amount of vapour given per gallon of fuel will be 24.7 cub. ft. per gallon in the case of heptane, and 22.6 cub. ft. per gallon with octane, and 20.8 for nonane.

The following interesting table is taken from the R.A.C. Report, on the Limit carburettor, fitted to a four-cylinder 80 mm. × 120 mm. engine, and is useful as showing the possibilities of an instrument of this type :—

TABLE LV.—PARTICULARS OF BENCH TESTS (LIMIT CARBURETTOR).

	Number of Test.								
	1	2	3	4	5	6	7	8	9
Revolutions of engine per minute	1519	1517	1515	1065	1062	1063	481	485	487
Brake horse-power (see description of trial)	20.22	14.04	8.47	16.83	9.97	6.23	7.66	5.56	3.20
Fuel consumption, pints per horse-power hour	0.653	0.694	0.948	0.625	0.697	0.759	0.765	0.893	0.915
*Variation of mixture, expressed as percentage variation from the mean mixture in the nine tests — above (weaker)	1.1	1.2	...	1.9	5.7	6.2	...	...	...
— below (stronger)	...	...	1.8	...	...	...	11.4	4.0	0.9
Exhaust gas analysis, carbon dioxide, per cent.	12.5	13.2	13.9	13.4	13.8	13.8	12.5	13.3	12.6
Exhaust gas analysis, carbon monoxide, per cent.	2.0	1.4	1.2	1.2	0.4	1.4	3.4	2.0	2.2
Exhaust gas analysis, hydrogen, per cent.	0.7	0.5	0.4	0.4	0.1	0.1	1.2	0.7	0.8
,, ,, methane, ,,	0.2	0.2	0.1	0.1	nil	nil	0.4	0.2	0.2
,, ,, oxygen, ,,	1.0	0.4	0.4	0.6	1.0	0.6	0.2	nil	0.4
,, ,, nitrogen, ,,	83.6	84.3	84.0	84.3	84.7	85 1	82.3	83.8	83.8

* NOTE—The mixture in each test was determined from the composition of the exhaust gases.
The engine was also run slowly without load, when the fuel consumption was found to be 1.002 pints per hour.

PART II

CHAPTER XIII

CARBURETTORS

The "Bailey-Dale" Carburettor.—This carburettor is somewhat unique, being of the single lever control mechanically automatic type. Two adjustable jets with their respective choke tubes are features of this design, and are arranged in such a manner that they are visible and adjustable whilst the carburettor is working.

It will be noted that a shutter is provided to give access to these jets and choke tubes, and they are therefore readily accessible.

The smaller or pilot combination of jet and choke tube is of such dimensions that at the lowest engine speed the velocity of air passing the jet is sufficiently high to ensure easy starting and the proper atomisation of the petrol, and this can only be accomplished by means of a reasonably high depression. The designer of this instrument considers that a depression of about 14 in. is the most suitable for this purpose. This jet is first brought into operation when the throttle is opened.

The main jet and choke tube combination, which are naturally of larger dimensions, are automatically brought into action by a further movement of the throttle, in accordance with the requirements of the engine.

In order to make the necessary corrections for high engine speed in this instance, arrangements are made in

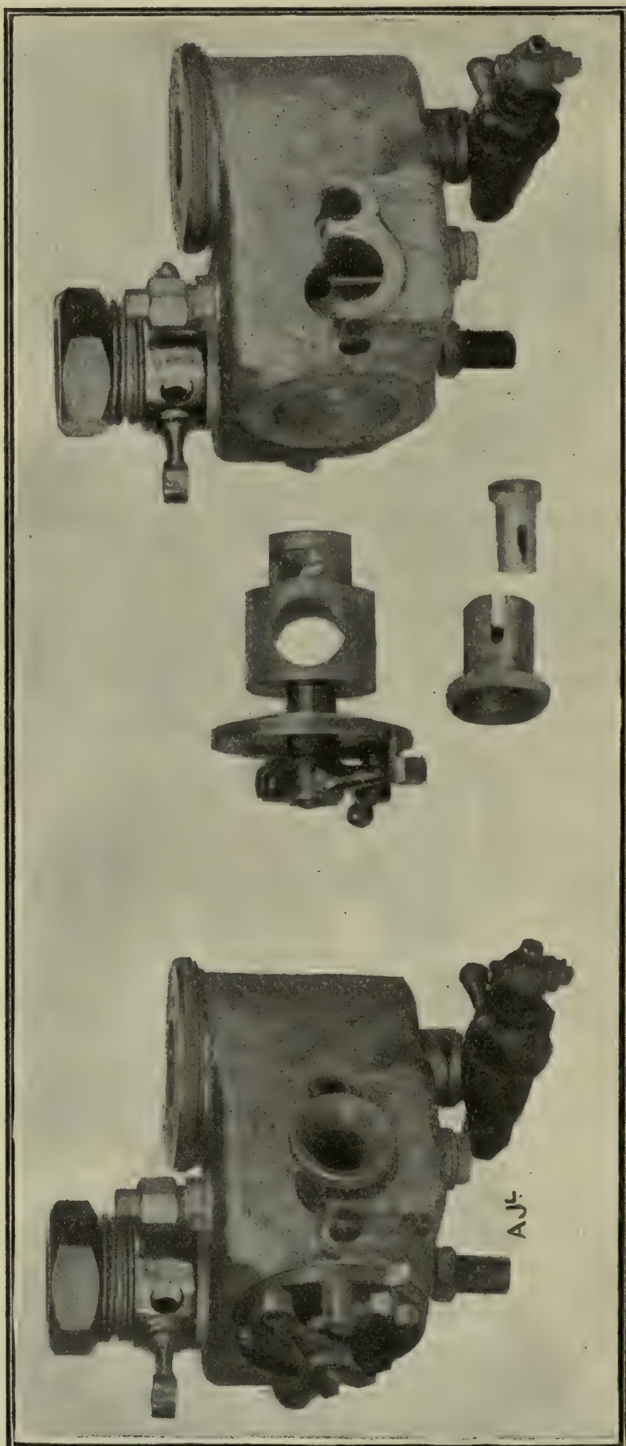

FIG. 27.—Bailey-Dale.

the form of an automatic air device working in conjunction with the throttle. The air shutter provided for this purpose can be adjusted to come into action at any point in the travel of the throttle, thus enabling any desired petrol or air curve to be obtained to suit any particular engine.

One of the features of this instrument is the split barrel throttle, which remains tight at all times, and therefore does not leak if any wear comes upon it. It will also be noticed that this throttle is of the type which closes on two sides, viz., the inlet and the outlet, and the throttle spindle is of large diameter made of steel working in a long bush so as to minimise wear and tear.

This carburettor is of the variable suction type, and the adjustments can be carried out as follows: firstly, adjustment of the pilot jet; secondly, that of the main jet; and thirdly, that of the auxiliary air supply.

The makers advise that the diameter of the main choke should be a fifth to a quarter of the diameter of one of the engine cylinders, and that in conjunction with the largest main choke tube the largest auxiliary choke tube should be also employed.

An adjusting screw is fitted in the pilot jet, and this should be so arranged at starting that an ample supply of fuel is passed, and when the engine is running with the throttle in such a position that the pilot jet only is in use, the screw controlling the flow of fuel through this jet can easily be regulated. Care should be taken that the automatic air shutter does not come into operation before the main jet comes into action, and as the adjusting screw of the pilot jet is gradually closed down the speed of the engine will increase until such a point as the most economical and efficient mixture is arrived at. On further screwing down the jet orifice, the engine speed will again fall off due to a weak mixture, and the mixture must not be weakened beyond this point.

The main jet can now be regulated by means of the

adjusting screw until maximum power is obtained with about half throttle opening, and finally the auxiliary air supply can be adjusted when the car is taken to a suitable hill.

Binks.—The Binks carburettor is of the two-jet type, and of its principal claims the first is that in place of an ordinary rotating or butterfly throttle, valves of the mushroom type are fitted one above the other on a vertical spindle. In one type of Binks carburettor the spindle is horizontal, but the principle is practically the same. In the first place, valves of the mushroom type are easier to keep tight on their seats, and the designer of the carburettor places great importance on the tightness of the valves. The two jets consist of a small one for slow running, with a separate choke tube and a main jet for ordinary working mixtures. By means of the small jet it is stated that all speeds up to about 15 m.p.h. can be obtained, and as the two throttles work conjointly, that which controls the small jet and choke tube naturally moves slightly in advance of the main throttle. These valves are so arranged that the suction of the engine tends to keep them closed, and a spring is provided to hold the main valve on its seat. This type of carburettor is one which lays itself open to a very large variation in adjustment, and as six choke tubes are provided with each carburettor, combinations with the various jets give a very wide range. Furthermore, great facilities are provided for making the necessary alterations, as it is claimed by the designer that an important point in carburettor construction should be facility for making adjustments as necessity arises.

A useful feature is embodied in the design of this carburettor, whereby a single operation of the lever brings first one and then the other jet into use, whilst a still further movement of the lever permits an extra supply of air to be drawn into the induction pipe. By means of this arrangement it is possible to ascertain, when running,

whether the air supply is sufficient or not at high speed, and if it is found that the mixture is too rich under

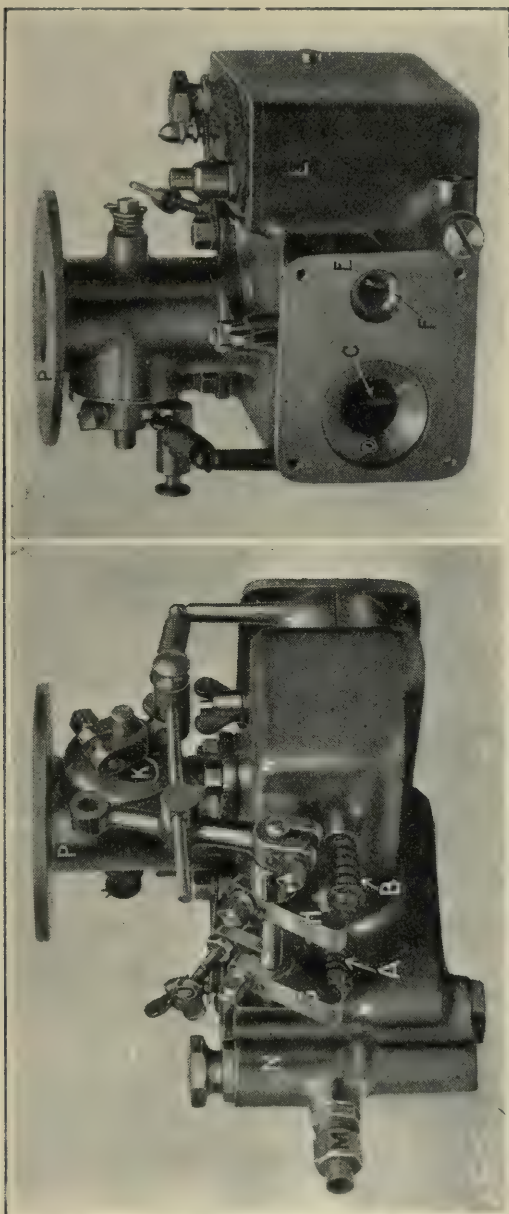

FIG. 28.—Binks.

these conditions, the pick-up will be increased as the extra air is admitted, thus showing that the main jet is too

large. In the design of this carburettor great importance is attached to a high velocity past the jet, and it is claimed that perfect carburation can only be obtained by the mechanical action due to a high air velocity. By means of the use of a truly shaped Venturi tube it is naturally possible to pass a very much larger quantity of air through a given aperture than would be the case were the choke tube improperly designed. It is claimed, therefore, that in the design of this carburettor a maximum amount of air for a given size choke tube is drawn into the engine. The heating of this carburettor by hot air eliminates a water jacket, with its attendant pipes and connections. It naturally does not signify as to how the heat is applied, as long as there is sufficient to supply the latent heat of evaporation of the fuel.

The Brewer Carburettor.—The principal features embodied in the design of this instrument are a variably progressive lift of the fuel needle in comparison to the lift of the air valve, a jet orifice whose coefficient of discharge under all ordinary conditions is approximately constant, and a fine atomising of the fuel near the orifice.

The construction of the carburettor is such that it works under a variable depression, as the author has found from experiment that the ordinary constant suction instrument has limitations except perhaps in very few instances. At any rate he is of firm opinion that when a so-called constant suction carburettor is called upon to perform high duties, it no longer remains working under its normal or designed depression.

Further, a higher depression than is usually suitable for a constant suction design, is often desirable, in order to effect atomisation of the fuel when the discharge rate is high, and the Brewer carburettor is designed to work at a depression as high as 25 in. of water at its maximum limit. Further its lower limit of working before the air valve lifts is 7 to 8 in. of water, and by keeping this

pressure low, the weight of the moving part and hence its inertia can be kept down.

Under slow running light conditions the depression in the mixing chamber is 4 in. of water, but owing to the great restriction caused by the Venturi tube round the jet orifice the air velocity at this point is high.

Observations made with water show that when an air stream is blown through the Venturi tube at ordinary working pressure, the water issues from the nozzle in such a fine spray that it can scarcely be seen.

The object of the progressive movement of the fuel needle scarcely requires enlarging upon, as the necessity of allowing a larger orifice for cold fuel than for warm fuel has already been explained in another part of this book. Also it has been shown that when the engine and carburettor are cold at starting, a larger proportion of fuel is required on account of imperfect vaporisation of the whole of the fractions.

The design of the carburettor can be grasped by reference to the accompanying sections (Fig. 29). F is the main carburettor casting enclosed at the top by the dismantling cap C, and having attached at the bottom the bowl of the float chamber M. N is the concentric float. Set in a socket formed in the body of the carburettor is the main air valve J, capable of being reciprocated vertically by the suction of the engine. The ridge or cam-shaped projection Q at the top of this throttle valve bears against the hooked end of the lever G pivoted at E. This lever in its turn bears against the flange formed on the jet needle carrier D, which is seen to be surrounded by a spring set between the flange already mentioned and the underface of the dismantling cap C. Within this carrier D is the vertical jet needle B, with grooves of gradually increasing depth formed in its lower end. It is cross-cut at the top for adjustment in the jet needle carrier, by means of the screwed end. Within the lower part of the air valve J is the Venturi choke tube L secured to it. The grooved

end of the vertical jet needle passes into the vertical fuel nozzle O, which is screwed into the lower portion of the body F of the carburettor.

The principal feature is the control of the fuel valve B by means of the air valve J. Contrary to the common practice, in which the air and fuel valves are directly connected, in this case the two valves B and J are so connected that their relative openings are capable of being varied, the movement of the air valve J transmitting movement to the fuel valve B through the medium of the hinged finger or claw G. The latter operates as a lever, the fulcrum or fixed pivot E of this lever being attached to some convenient part of the carburettor body, and the toe of the lever pressing against the carrier D, which, as mentioned, holds the fuel needle B for regulating the flow of the fuel through the nozzle or jet O.

Movement is imparted to the needle carrier D by the air valve J through the medium of this lever, and for this purpose the air valve has formed upon it a ridge, or cam-shaped projection Q, already mentioned, which is so located upon the air valve J that a rotation of the latter brings the point of contact of the ridge, or cam-shaped piece, into different positions upon the heel of the intermediate lever G, thus changing the extent of its leverage.

The original setting of the fuel valve B with regard to its orifice will not be altered at the zero, or slow running position, by a rotation of the actuating air valve, but the differential movement through the medium of the heel of the lever G increases from zero to a maximum as the air valve throttle rises from its seat.

When setting the fuel feed and air supply proportions any rotation of the air valve will give a progressive increase, or decrease, of lift to the fuel valve. The setting remains constant until again adjusted, the air valve J being prevented from rotating by notches in the cam-shaped piece Q into which the lever G drops. Co-operating with the vertical fuel nozzle O is a tubular extension of the air

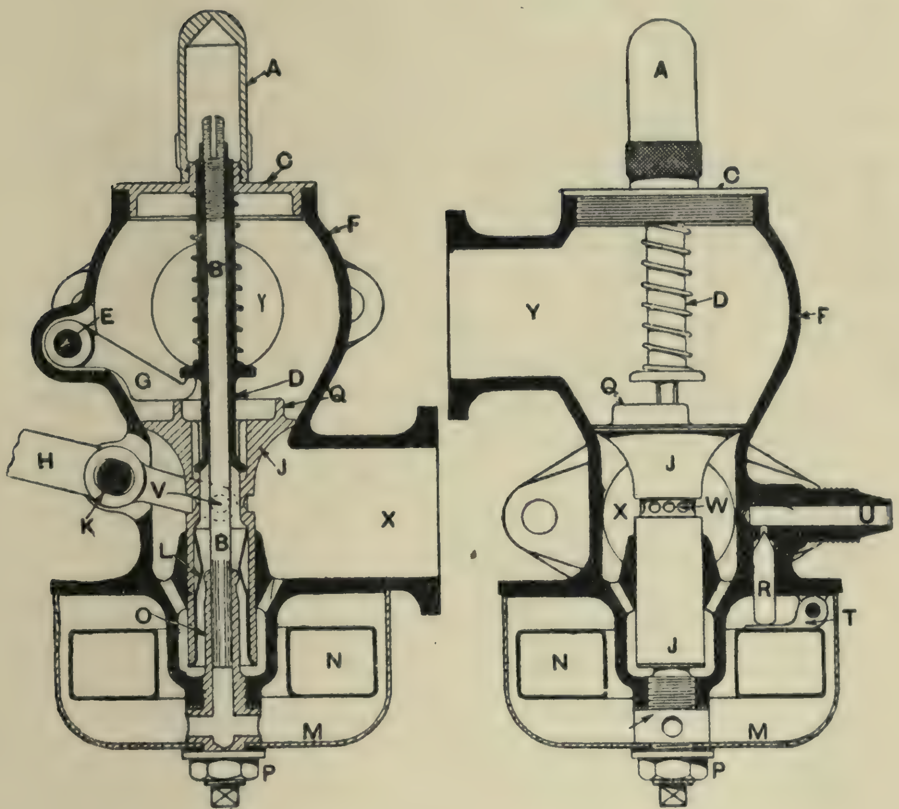

FIG. 29.—The Vertical Sections of the Brewer Carburettor (diagrammatic).

A. Dust cap.
B. Vertical jet needle with grooves of gradually increasing depth.
C. Dismantling cap.
D. Jet needle-carrier in which needle can be adjusted vertically.
E. Fulcrum spindle of lever G.
F. Main carburettor casting.
G. Lever which receives motion from air valve J, and imparts motion to carrier D, and jet needle B.
J. Air valve.
L. Venturi choke tube secured in the stem of air valve J.
M. Bowl of float chamber.
N. Cork or metal float.
O. Vertical fuel nozzle secured in base of body F.
P. Nut securing float chamber bowl.
Q. Cam - shaped projection on air valve J.
R. Float chamber needle valve.
T. Float lever.
U. Petrol feed.
X. Main air inlet.
Y. Induction pipe connection.

valve J provided with a conical sleeve or choke tube L, which rises and falls around the outside of the fuel nozzle, according to the rise and fall of the air valve J, leaving an annular opening through which the primary air passes from the air supply and mixes with and atomises the fuel coming from the inside of the nozzle along the grooves of the valve spindle.

When running dead slow, this sleeve L admits the whole of the mixture which passes to the induction pipe, but as the air valve J is raised, it opens up not only the main air supply X, due to the air valve leaving its seating proper, but also admits an increased initial supply due to the rising of the conical choke tube L. The raising of the air valve J also raises the fuel valve B and admits more fuel, as before mentioned.

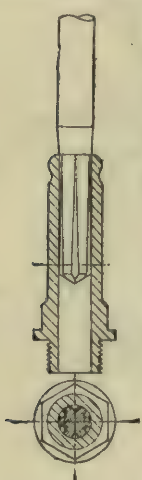

FIG. 30.

An advantage of the design is that the complete carburettor can be manufactured with very little machining, since its operation is independent of accurate fitting of the parts controlling the air supply.

Figs. 11 and 30 are enlarged views of the vertical jet and needle which are used in this carburettor. The jet tube is of larger diameter than usual, 4 mm. bore being a standard size. Into this jet, as shown, there passes a long fluted needle which projects 1 in. in the closed position, the total maximum lift being $\frac{3}{8}$ in. to $\frac{1}{2}$ in. Although the fluted needle in itself is not new, the shape of the flutes is very important, as it gives a practically constant coefficient of discharge of the orifice at all working positions of the needle under fuel heads of from 10 in. to 25 in. of water pressure.

The coefficient of discharge of an orifice is a factor which depends, firstly, upon the flow of fuel per unit area, and, secondly, upon the square root of the pressure difference between the atmospheric pressure in the mixing chamber in the vicinity of the jet.

Now, if the depression or suction is constant, the coefficient of discharge of the orifice is a certain constant depending upon the amount of the suction, whatever may be the area of the orifice or the amount of fuel flowing. However, if the suction varies, the constant is different for each value of the suction; for instance, at a 10-in. suction the constant is 0.568, and that figure multiplied by the flow of fuel in gallons per hour per square mm. of orifice will give the coefficient of discharge of the orifice.

When the suction increases to 15 in. of water-head the constant becomes 0.453, and at 20 in. it is 0.400, and so on. This variation of figure, as before mentioned, is governed by the square root of the pressure difference in the same way that the flow of the air through the carburettor is governed. If, therefore, a constant mixture is to be produced the flow of fuel per unit area through the orifice, under increasing pressures, must increase approximately as the square root of the pressure difference, *i.e.*, at the same rate as the flow of the air increases.

Tests made with a liquid flowing through this type of orifice show that with the constant coefficient of fuel discharge which is very nearly obtained, the proportions of the mixture will remain the same under all ordinary working conditions, owing to the actual flow of fuel increasing at the same rate as the flow of air.

The flutes are of segmental section with rounded corners, increasing in depth and width from their zero position to the point of the needle, and the coefficient of discharge of such an orifice is of the order of 0.440, that of a round hole being of the order of 0.770, when the length of the orifice is four or five times its diameter. The object also of such an orifice as this is to give high jet friction with a good spraying effect, and, by means of shaping the outside of the jet tube as shown, and fitting a small choke tube which lifts with the air valve, concentration of primary air flow round the fuel orifice is obtained.

The object of the proportionate adjustment is to de-

crease the opening of the fuel orifice when the instrument and the fuel become warmed up, as the flow of fuel through an orifice becomes from 10 per cent. to 15 per cent. more rapid at the upper limit of temperature reached in ordinary motor car work.

Another type of this device has been designed for production in die casting, and although the principle is the same, some modification in detail has been embodied, firstly, in order to enable an extra hot air supply to be admitted around the jet, which, by the way, can be alternatively replaced by paraffin vapour, and this transforms the instrument into a paraffin carburettor. Secondly, the instrument has been fitted with a butterfly throttle of the conventional type in order to bring it more into popular line, and, further, one type can be made universal for any arrangement of fuel or air openings to suit individual engines.

The differential movement in the latest model of the Brewer carburettor is so designed that a single direct movement of one control both increases the proportion of fuel progressively at all speeds of the engine, and at the same time gives a larger fuel opening at zero position of the needle, for slow running.

The larger model Brewer carburettor is modified in order to simplify the control gear and to provide a straight line movement for adjustment of the regulating device. In order to obtain this, the fulcrum of the actuating lever X is placed upon the air valve itself and the adjustable lift is given by moving a contact piece forward or backward along the free end of this lever. This can be done by means of a Bowden wire control, and the device which holds the end of this control in position is capable of movement in a slot, fully covered by its locking device, so that the slow running position of the needle can be located by fixing the control in such a position that the forked end of the lever is suitably displaced so as to raise or lower the needle permanently in the jet.

It will be seen that the differential movement is then provided by sliding the contact piece V forward or backward along the lever O.

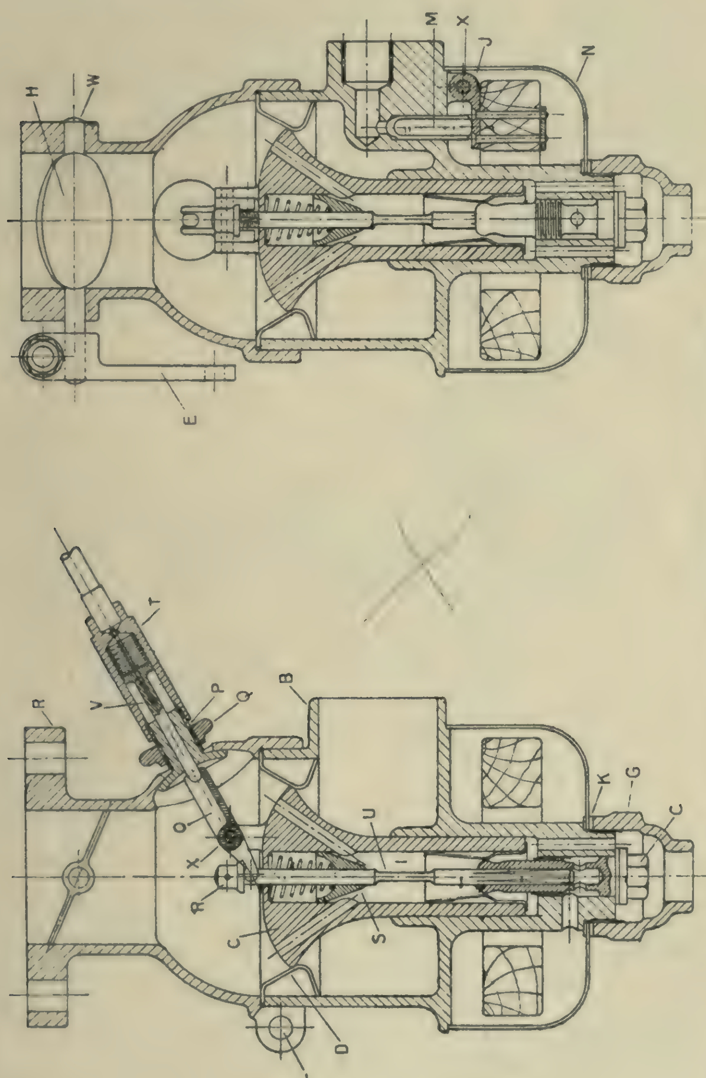

FIG. 31.—Brewer Carburettor, Floating Type.

An alternative method is to make the axis of movement of the piece V oblique to the face of the lever O upon which it works. The object of this is to alter the zero or slow running position simultaneously with any alteration for proportions of mixture. Thus, if it is desired to

weaken the mixture by giving the fuel needle a smaller travel, the needle at zero position will be allowed to enter further into the jet orifice, and thus weaken the mixture at slow running. A design has been prepared by the author for such an arrangement in connection with the S.U. carburettor which is particularly adapted for such a device. In order to carry this into effect, a separate needle carrier is provided, concentric with the usual spindle holding the weighted piston, this carrier being extended

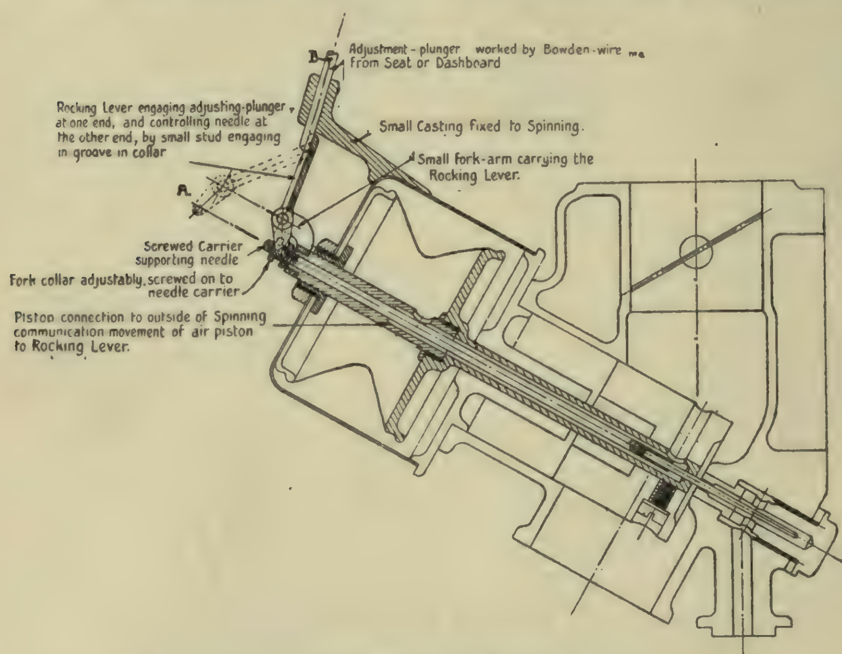

FIG. 32.—S.U. with Brewer's Patent Adjustment.

outside the top of the instrument, and actuated by a lever supplied with an obliquely acting control slipper. A straight movement of this slipper enables the needle position in the jet to be varied both for starting up, giving a richer mixture, and in running until the carburettor is warm. The adjustment can then be made from the driver's seat, setting the movement back into its normal position.

By such a means the control of the S.U. carburettor can be made suitable for all temperatures and fuels without changing the needle.

The Brown and Barlow 1913 type of carburettor is of very simple construction, and its principle of working consists in there being two main jets and a pilot jet, the two main ones being brought into action in turn by the movement of the throttle, the pilot jet always remaining in operation even when the throttle is nearly closed. These main jets consist of two small apertures, each one covered by a sealing, which latter can be rotated for the purpose of adjustment from zero to the full aperture of the jet

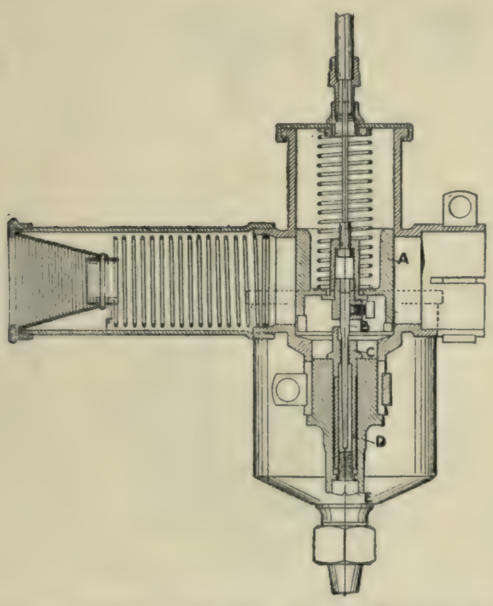

Fig. 33.—Brown and Barlow Pin Operated Type.

opening, the amount of such opening being indicated by a suitable number. The throttle itself has a rotary motion, and is so arranged that an additional supply of air comes into use if required after the throttle is partially opened, and furthermore an automatic auxiliary air valve is fitted which is adjusted in the works before the carburettor is sent out. The system of operation is as follows: Each main jet is entirely independent of the other one, and when the throttle is somewhat less than half open, the primary jet, which is the one situated nearest to the float

chamber, is in use, and as the throttle is further opened, the second jet comes into operation, and this is only actually working when the engine is required to give its full power. In order, therefore, to set the instrument and the jet openings, it is first necessary to so set No. 1 jet that the fuel consumption is satisfactory under ordinary working conditions; the second jet can then be set to give a suitable aperture so that the engine gives its best power when the car is climbing a hill. Whatever be the

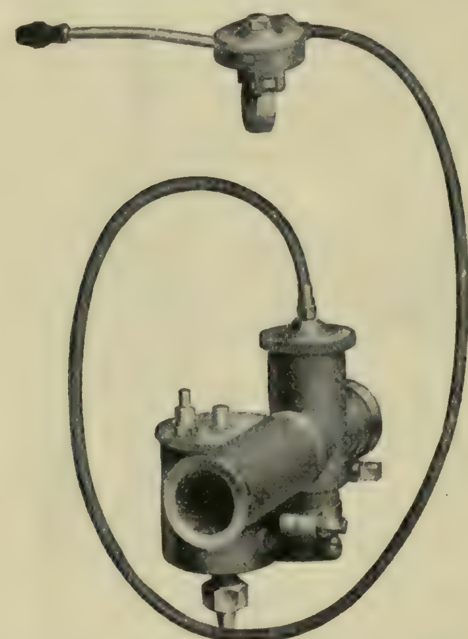

FIG. 34.—Brown and Barlow Bicycle Type.

setting of each jet, the working of the instrument is claimed to remain unchanged as regards the effect of the aperture of one jet or the other; that is to say, that any adjustment of the full power jet does not in any way interfere with the half power jet. A similar adjustment is provided for the pilot jet, and this can readily be made by means of a screwdriver: the adjustable jet and choke tube form a complete unit so that they can be taken out and replaced without altering the setting. This

arrangement makes a very compact instrument, and it will be seen that the over-all dimensions of this carburettor compare favourably with any of those upon the market.

The float chamber of this carburettor has a loose cap held in position by a single spring, which forms a convenient method of fixing the float chamber cap so that it can be removed without the use of tools.

Messrs Brown & Barlow have for a long time been associated with the manufacture of carburettors for motor bicycles, and, in addition to the 1913 model already described for car use, they make a single jet instrument of the type illustrated, which comprises a modulating pin with an additional air device.

The 1913 model is of the hot-air heated type.

Claudel-Hobson.—The Claudel-Hobson (Fig. 35) carburettor is an intermediate type between the "restricted flow type" and the two-stage type to be referred to later. In the first place, the restricted flow is obtained by means of the shrouded jet, but in place of an obstruction in the actual petrol passage there is an obstruction situated a certain distance beyond and immediately opposite the jet orifice. In the early days of carburettor development jets were tried, provided with an obstruction intended to reduce the efflux of the liquid fuel by interposing a resistance to the issuing stream, and thus tending to throw the liquid back upon the orifice and decrease its coefficient of discharge. The Claudel-Hobson jet is provided with a damping screw, with an end so shaped and so placed within the shrouding tube that a damping action occurs which comes into play at high rates of discharge. If a curve of discharge from a single cylindrical orifice be studied, such as the curves which appear on p. 59, it will be noticed that these curves have a rapid upward trend, which should be damped out by some extraneous means in order to provide perfectly uniform mixtures throughout the entire range of engine speed.

The Claudel jet is further discussed in other parts of this book, to which reference should be made.

The rotating throttle operates upon the air intake and the gas outlet in a similar manner to that provided in the White and Poppe instrument. There is, however, the difference that the throttle in the Claudel instrument, as it is gradually closed, concentrates the air stream more and

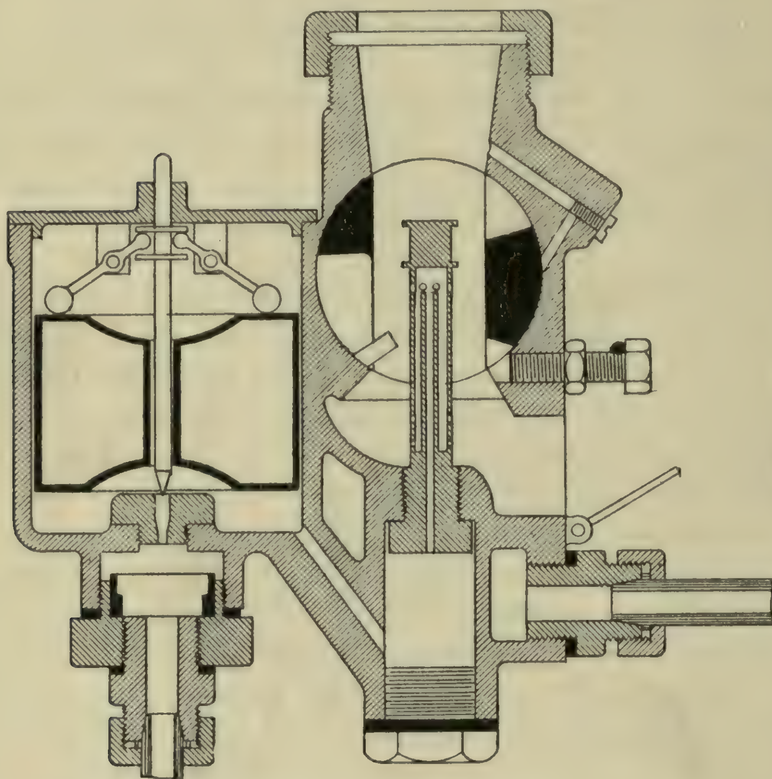

FIG. 35.—Claudel-Hobson.

more into the vicinity of the jet. By this means we have the effect of a varying choke tube which has been tried in the earlier patterns of carburettors, as exemplified by the Longuemare model R, and also in the Sthenos. The simple form of Rover carburettor, fitted with a rotary double purpose throttle and inclined jet, also operated in a somewhat similar manner as regards the concentration of the

air flow into the vicinity of the jet as the throttle was closed down.

The latest type of Claudel-Hobson carburettor differs somewhat from the earlier ones, in that the passage through the instrument is of greater effective area than it is nominally, and those carburettors used on some of the racing cars during the past season cannot fairly be compared, as regards their size, with the ordinary standard type.

In carburettors such as the Claudel-Hobson it is somewhat difficult to take advantage of Venturi tube formation except at or near full throttle opening, and when the author was experimenting with this carburettor some few years ago, it was originally manufactured in a truly cylindrical form right through the carburettor casing. The barrel-shaped throttle of this instrument has a parallel hole through its normal diameter, and it was decided to cone out the discharge side of the body to improve the carburation. This external coning, combined with a slight undercutting to give an angle of entry, increased the discharge rate of the instrument, and all these carburettors are now constructed in this manner. For mechanical reasons the bore through the throttle has to be parallel, so the coning is not true, and, moreover, the angle of discharge is usually made greater than necessary for a true formation.

One model (Fig. 36) shows how the Venturi outlet can be improved in shape by lengthening the body of the instrument.

One of the features of this carburettor is the method of hot-water jacketing the lower part, through which the petrol passes on its way to the jet, with the result that the viscosity of the fuel is diminished as the temperature rises.

If in working, the temperature of the jacket water is constant, or nearly so, at all times of the year, it is unnecessary to change the size of the jet at any time. In actual practice this is a fact, and one advantage of the instrument is that it is unaffected by changes of atmospheric condi-

tions when a working temperature has been reached. When, however, the engine starts from cold, and the

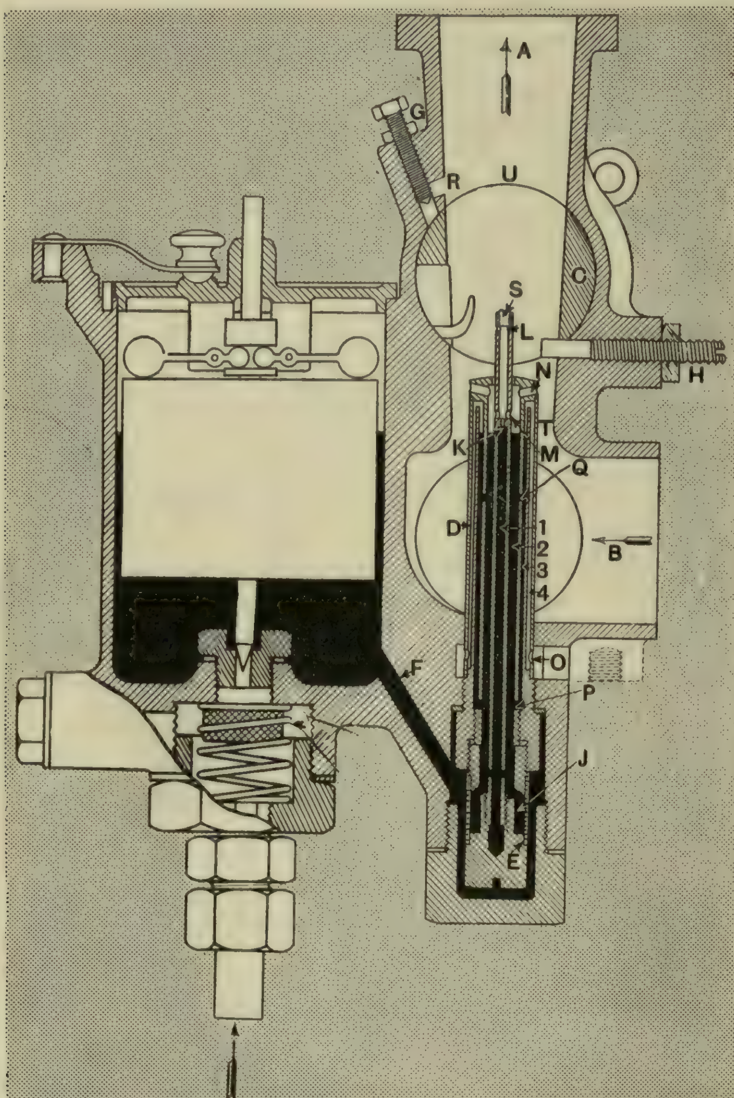

FIG. 36.—Racing Claudel.

viscosity of petrol is greater, it is evident that some small difficulties in carburation may occur.

Practical demonstration of this is given when it is found

that the engine pulls best when the throttle is not fully opened; the explanation of this fact is that it is necessary to increase the local suction in order that the flow of fuel should be adequate.

Ease of starting is, therefore, obtained by providing an air shutter to increase the suction when turning the engine by hand.

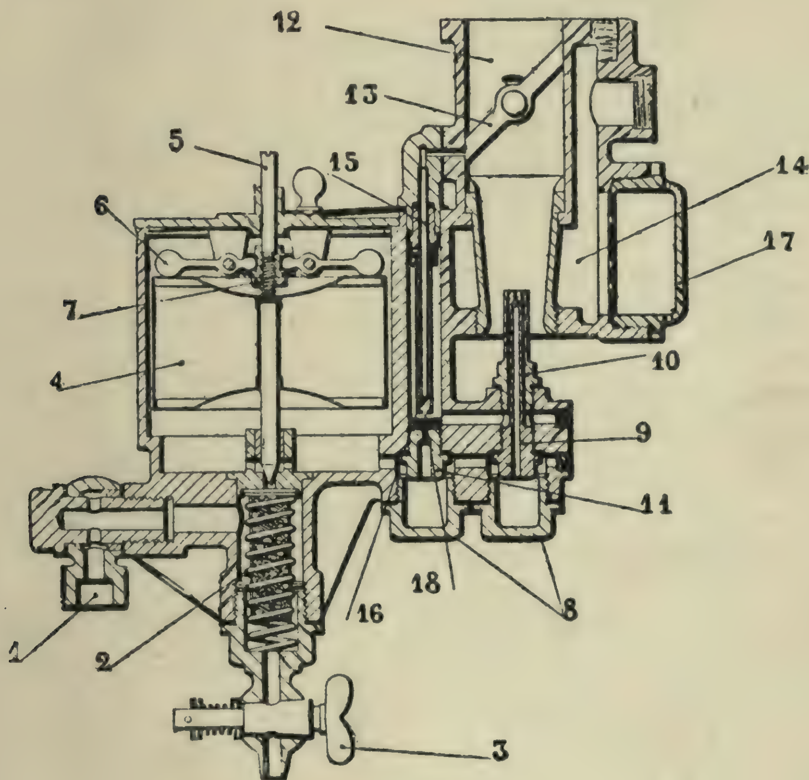

FIG. 37.—De Dion (Zenith).

The De Dion Carburettor is a modified Zenith, and is hot-water or exhaust heated, and it will be noticed that the air entry passage is somewhat freer than the usual type. A notable refinement in this instrument is the provision of a capacious fuel filter, situated below the needle valve of the float chamber.

This filter is easily removable, consisting of a main

body, a cleaning plug, a filtering gauze and a retaining spring for the same, and a draw-off cock.

As in the ordinary Zenith, suitable plugs of cup shape are provided below the two concentric jets and the limiting orifice so as to catch any sediment in the fuel, which can thus be easily cleared.

Delaunay Belleville.—The object aimed at in the design of this carburettor is the response of the engine to the opening of the throttle, and the ease of dismantling of the whole apparatus. Furthermore, the method of operation and of adjustment are of the simplest kind.

Referring now to Fig. 38, the fuel enters the instrument through the pipe A, and by way of the cock to the centre chamber B, in which is placed a filter C.

At the foot of the filtering chamber is a long tubular sump D, closed by a screwed cap and washer, so that ample provision is made for catching any sediment which may enter with the fuel.

It will be noticed that the fuel passes from the outside to the inside of the filter C, and by means of the spring closed ball valve H and the needle G into the float chamber.

This is the type of float chamber and needle valve referred to in Chapter X., Fig. 24, where the weight of the float keeps the ball valve off its seat until such time as the fuel level rises, and permits the action of the spring to close the ball valve by releasing the pressure due to the weight of the float.

The main jet is shown at K, and two fuel passages are provided by J, J, one leading also to the surface carburetting chamber M.

Within this chamber is the vapour jet N, in communication with the vapour tube O; the air enters the carburetting chamber by the gauze-covered orifices of circular form, and an extra air valve T, working against the action of an adjustable helical spring of considerable length, and

a glycerine damper valve V. The additional air which passes through the valve T mixes with the vapour rising up the tube Q, through the air filter R, and a hot-water

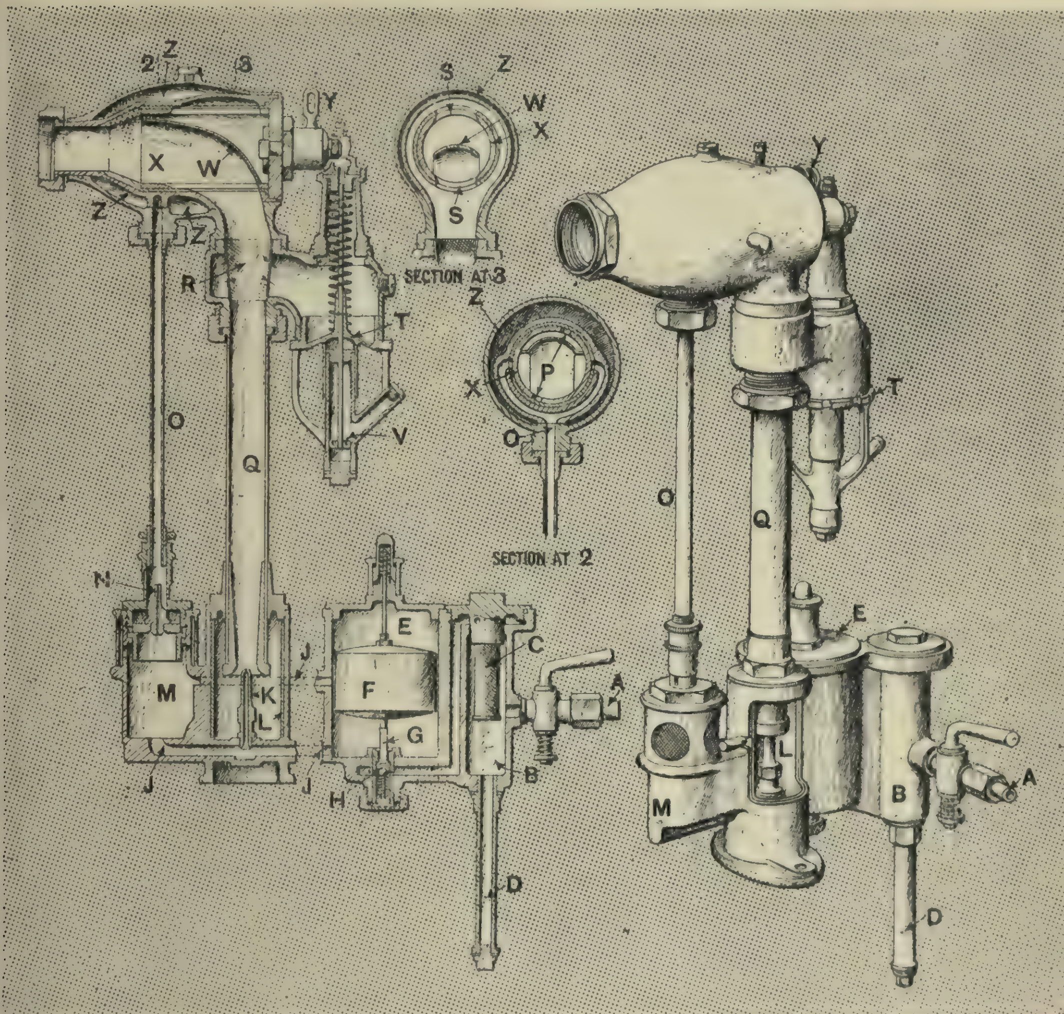

FIG. 38.—Delaunay Belleville.

jacketed throttle chamber is fitted where these mixture pipes join at X; a direction plate W being fitted so as to eliminate the sharp corner which would otherwise be presented in the flow path.

In the section shown at 2, the passages communicating with the surface carburetting tube O can be seen, and it is through these passages that the mixture is led to the engine for starting and slow running purposes.

In the section shown at 3 the full opening S from the throttle to the main jet mixing tube Q can also be seen.

With reference to the accessibility of the instrument, it will be noticed that a door L is shown covering the main jet K, and the vapour jet can be reached by unscrewing the cap of the surface carburetting chamber.

The automatic air valve with its damper, control spring, and spindle are removable with the valve seating itself when this is unscrewed.

This instrument comprises a certain amount of what would be the inlet pipe in the ordinary way, and it appears to contain a good many parts which have been eliminated in modern practice.

The Excelsior Carburettor.—This is somewhat typical of American carburettor design, and like many American carburettors has a concentric float situated around the main fuel orifice. The distinctive features claimed for this instrument are the ball-governed Venturi tube, the clock spring-controlled air valve, and the Excelsior formula for setting the carburettor.

Referring now to the figure, it will be seen that the fuel enters at the lower connection, and the float, which is a spinning, directly lifts the float valve which is situated in a removable seating in the base of the float chamber.

An adjustment can be made here so that the valve can be set to cut off the fuel in any desired position.

The primary air enters the circular orifice at the right of the figure, and is drawn by the suction of the motor past the spraying nozzle located in the restricted portion of the Venturi tube, and the amount of the opening of the spray nozzle is adjusted by a needle valve shown in the figure.

It will be noticed that the Venturi tube has a ball fitting in the V-shaped depression in the Venturi tube, and is so arranged that the air passing to the engine must flow round the ball which restricts the flow of air, thus reducing the suction on the spray nozzle, and consequently diminishing the flow of fuel drawn into the engine. As the demand of the engine increases the ball is lifted by the suction towards the larger end of the Venturi tube, thus

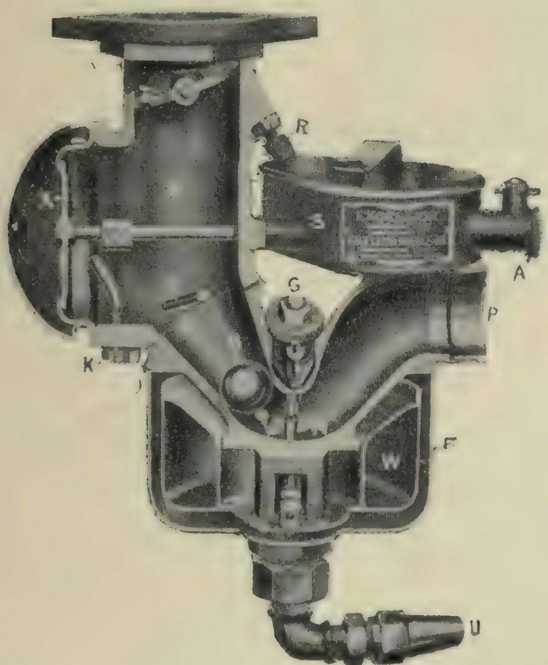

FIG. 39.—Excelsior.

gradually increasing the area of the air passage, and it is claimed that the movement of the ball regulates the quantities of air and fuel in their proper proportions.

An auxiliary air valve is fitted, which is under the action of a finely tempered coil spring fitted in the cylindrical housing shown on the top of the instrument, the degree of tension of which spring can be adjusted. It will be seen that in the vicinity of this additional air

valve is a mixing chamber of considerable capacity, so as to provide a thorough mixing of the additional air with the mixture passing through the engine. The throttle is of the butterfly type, fitted with a check screw. A special feature is made by the manufacturers of this instrument with regard to the construction and design of the spring used for the additional air valve. The movement which is imparted to this spring by the valve is multiplied, so that the tension of the spring can be extremely light when the valve is closed, and this tension increases rapidly as the valve opens.

The Everest Carburettor.—This carburettor is a very interesting example of a single lever or progressive type of instrument, its chief attraction being extreme simplicity and the wide range of adjustment. In its main features it is similar to many other of the single lever type, in that the air inlet to the carburettor, the gas outlet, and the jet exposure, are all increased or decreased simultaneously as the throttle lever is moved. The carburettor itself is fitted with a main jet tube A, in which fuel is maintained at a constant level by means of a float chamber fitted with toggle levers of the overhead type, and the level is such that the fuel will not overflow through the vertical jet holes drilled through the upper side of this tube.

The petrol tube A is arranged transversely in the mixing chamber B, from which gas passes out by the connection C to the engine, which is situated in a practically straight line with the opening D, and within the mixing chamber is a sliding piston, the lower edge of which, E, controls the air inlet, and the upper edge F controls the gas outlet, the piston being actuated by a suitable lever G. The piston throttle itself is fitted with sleeve H, so that when the throttle is moved to the right to open the passages C and D, a greater length of the jet tube A is uncovered, thus exposing the jet orifices in proportion as the carburettor opening is increased.

It will be noticed that the sleeve H is not directly attached to the piston, but is fitted to an intermediate sleeve J, connected by a peg K to the piston, so that when

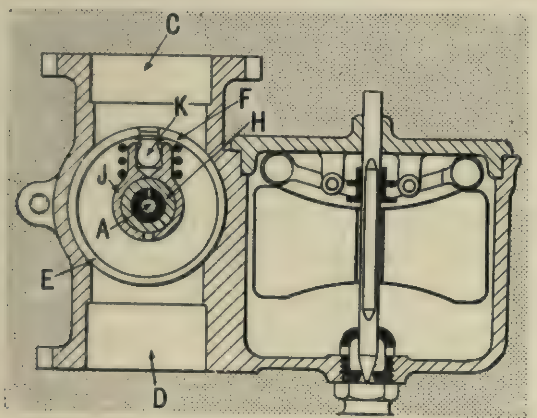

FIG. 40.—Everest.

the sleeve H is screwed further into or out of the sleeve J, its position relatively to that of the air sleeve can be changed. It will, therefore, be seen that in the general

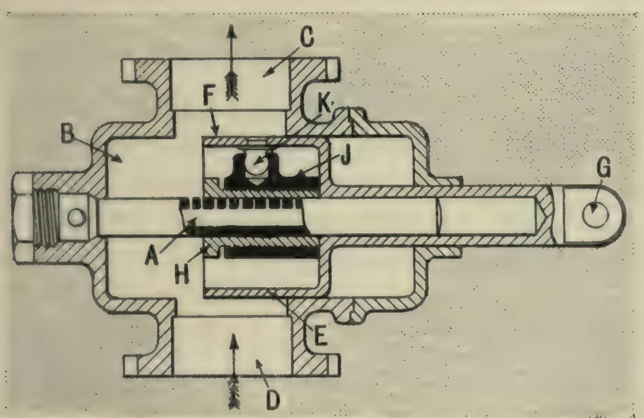

FIG. 41.—Everest.

arrangement this instrument is somewhat similar to the Polyrhoe, and can be adjusted so as to give any desired initial lap of fuel opening, but in this case the jet holes

can be increased as desired to give any required proportions of the mixture at various positions of throttle openings; for instance, a rich mixture can be obtained for slow speed running, and a weaker mixture for intermediate speeds, by suitably placing the jet holes.

Facile.—The Facile (Fig. 42) is one of that type of carburettor in which the movement of the throttle produces a variation of the air inlet ports, and at the same time regulates the discharge of petrol from the jet orifice. The regulation of fuel discharge is performed by placing a direct obstruction immediately above the orifice, at a greater or less distance according to the amount of petrol required.

In the past various devices, such as a cap or an atomising cone, have been tried for this purpose, but in the Facile carburettor a swinging, eccentrically-shaped arm is situated in such a position that as the throttle is opened the distance between the jet orifice and this arm increases, owing to the eccentricity of the periphery of the arm. It is claimed that by this means the jet is controlled as to its discharge, and the fuel is more completely atomised. This instrument differs in principle from any of those which we have had under consideration, as although the depression in the instrument is not by any means constant, the petrol flow is partially regulated throughout the whole range of throttle opening and engine speed. The word "partially" is justly used, because it has been found in practice, and is more or less a well-known fact, that the position of an obstruction outside the jet orifice does not have a very marked effect upon the petrol discharge. True it is that in a jet of the Claudel type the correct distance between the jet orifice and the baffling screw should be carefully observed, but as a means of regulating the flow, one cannot usually recommend throwing the petrol stream back upon itself. We know that if a jet orifice is placed in a vertical position, and that, say, water

issues directly from it, the falling globules tend to lessen the rate of discharge by striking the issuing stream. In a carburettor system one would suppose that the velocity of air carried with it the atomised fuel, and the fuel would be effectively removed from the vicinity of the jet and thus not have any baffling action. In the Facile carburettor arrangement the swinging quadrant can only, therefore, be considered as a valve whose lift can be varied

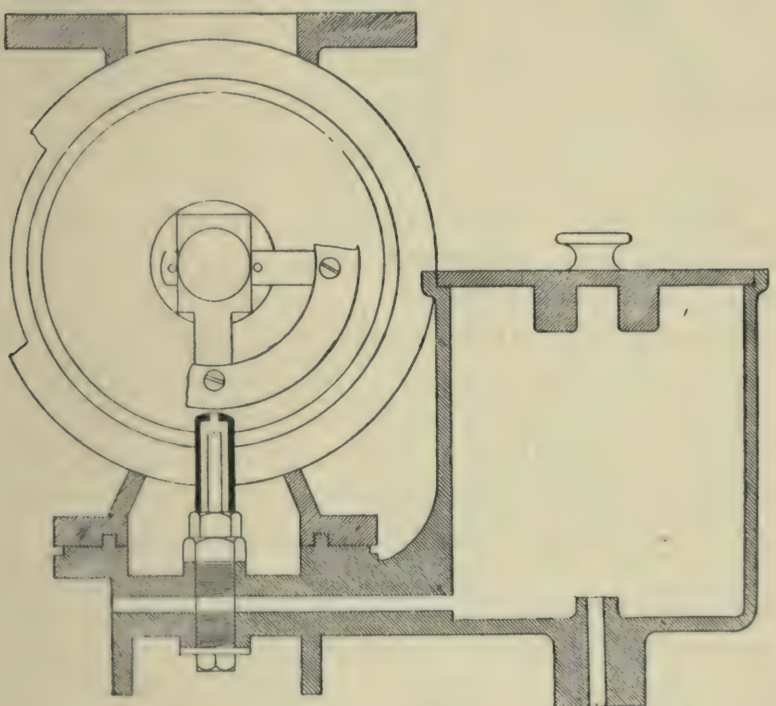

FIG. 42.—Facile.

in a very neat manner. Supposing, now, that the carburettor is set for its slowest running position, the quadrant will be swung down by the throttle, and the distance above the jet orifice can be regulated by altering the distance of the jet itself. In order to do this a spanner can be inserted through a small slot in the side of the instrument, and the jet turned bodily round so as to screw it up or down by a small amount. This can, of course, be done when the car

is running, and no locking nut is required. At the other end of the range an adjustment of the quadrant is possible, there being a small nut projecting through the side of the throttle chamber which operates directly upon the location of the eccentric arm, thus making the eccentricity variable. Between the points of maximum and minimum duty, the intermediate positions will be practically self-adjusting, provided always that the range of working of the instrument is along a straight portion of a fuel discharge curve from the particular instrument. If this is not so, the air ports could be suitably shaped to comply with any particular conditions, so that if a small instrument were used in connection with an engine of large capacity, a big depression could be prevented by providing air ports of sufficient size, which could come into use only when the throttle was full open, and the engine running all out.

G. and A.—The G. and A. carburettor (Fig. 43) exemplifies one of the earlier attempts in carburettor construction to permit working at a more or less constant depression where the action of gravity is employed against a moving weight. This instrument does not naturally work at a truly constant pressure difference, but the variation at higher engine speeds is less than it would be in a fixed jet and choke tube type on account of provision being made for an additional air supply to the mixing chamber. In the G. and A. system a conical choke tube is provided with an inclined jet at its throat, the inclination being of the order of 45 degrees to the vertical, and by this means it becomes possible to remove the jet when a plug situated opposite to it is withdrawn, a special tool being provided for this purpose. The conical choke tube extends well up into the mixing chamber, and round the base of an annulus in this chamber a number of holes are drilled of different sizes, which are covered by balls of various sizes, held in position by a cover plate, and as the suction increases so the balls rise from their seats, allowing an additional supply of air to

enter the mixing chamber. The mixing chamber contains a throttle, which may be either of the rotary or piston type, and the sides of the chamber are hot-water jacketed for use in a motor car, but for aviation purposes this carburettor is generally used without a jacket: the air enters a bell

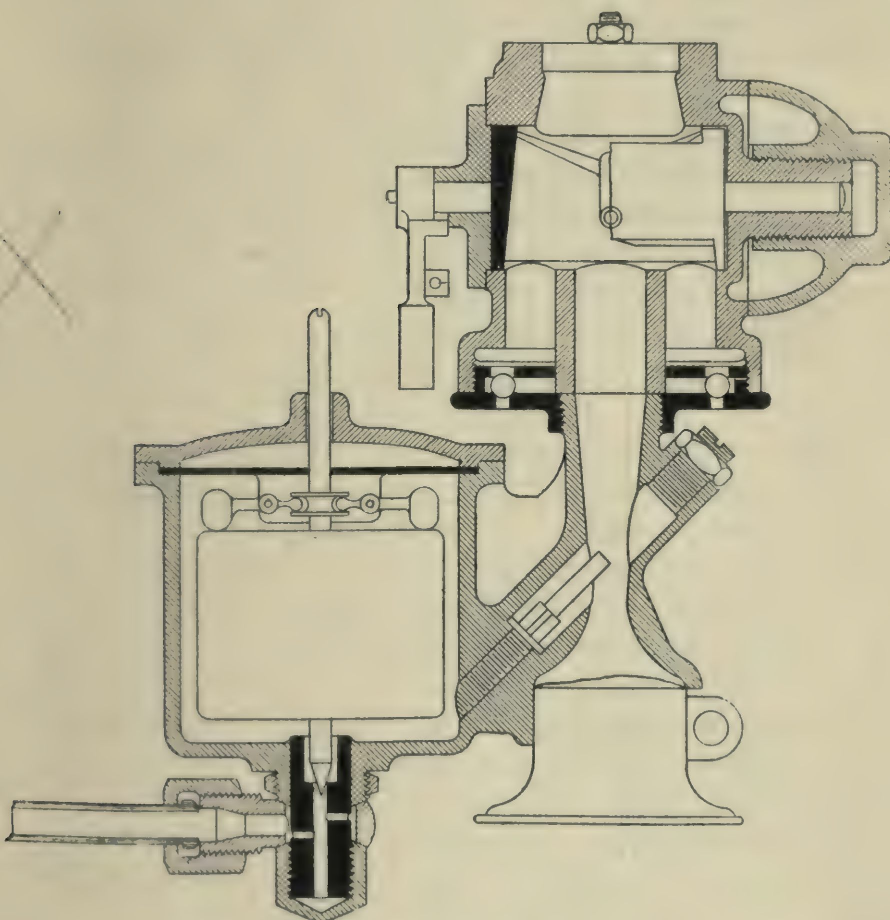

FIG. 43.—G. and A.

mouth at the lower part of the instrument, and has a straight through path. The carburettor itself has the merits of simplicity, and has proved quite satisfactory in many cases where it has been employed. It will be seen that in the lower limits of working the air velocity past the

jet is comparatively small when the choke tube is made sufficiently large to work efficiently at high speeds, and, furthermore, it will be noticed that the supplementary air supply does not come into contact with the petrol spray. As the ball seats are unprotected from impurities in the air, they may possibly become fouled, and a certain amount of care should, therefore, be taken in fixing this instrument, so that it is not unduly exposed to external interference.

Holley.—The Holley carburettor is manufactured in large quantities in America, and has been seen here on the Mitchell and Ford cars. This instrument in the modern type differs from a number of American carburettors in that there is no supplementary air valve, and it is claimed that the shape of the jet of itself prevents an excessive flow of petrol when great differences of pressure exist in the instrument.

This regulation is due to the fact that a certain amount of air is allowed to pass through the cup-shaped nozzle as the level of the fuel in the float chamber falls when the demand of the engine is great. By means of a small tube, not shown in the drawing, communication is made between the annulus round the outside of the cup-shaped jet and the inside of the float chamber above the level of the fuel under high speed working conditions. The direct fuel communication between the float chamber and the jet is through the small drilled plug, and it will be seen that there are two separate channels in the sides of the fuel nozzle through which either petrol alone or petrol and air are allowed to pass. At low speeds no air passes through the jet, but as the speed increases the upper orifice becomes uncovered owing to the fuel level falling, and air thus enters the two slots in the side of the jet tube together with the petrol. In this arrangement there is undoubtedly a certain amount of baffling action by reason of the shape of the jet orifice, which causes an obstruction to the free flow of the fuel. Furthermore, the presence of the air would still further

retard an abnormal efflux at high speeds. This instrument has been developed to work at engine speeds between 200 and 2,000 r.p.m., and a test on a Reo car with four

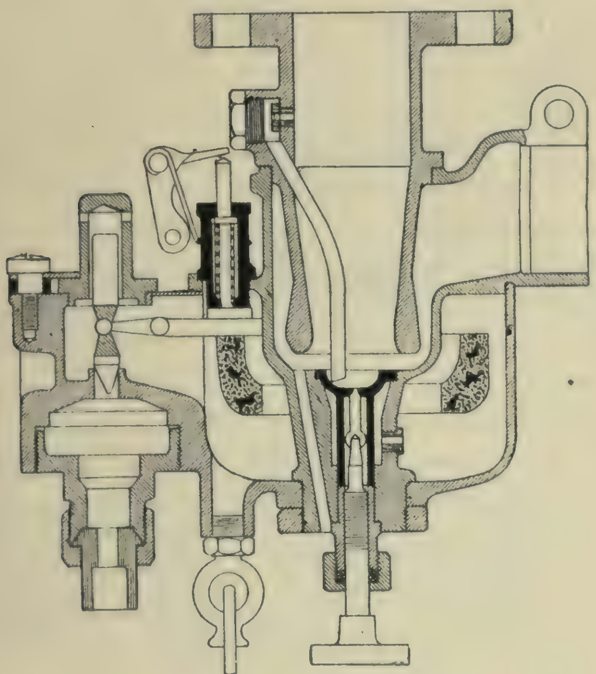

FIG. 44.—Holley.

cylinders 4 in. diameter and 4.5 in. stroke, with a gear ration of 3.7 to 1, gave fuel consumptions as follows :—

At 15	m.p.h.	19.2	miles per	gallon.
,, 20	,,	19.2	,,	,,
,, 25	,,	17.5	,,	,,
,, 30	,,	15.5	,,	,,
,, 35	,,	14.0	,,	,,

Looking now at the power developed with this engine, this was as follows :—

At 600	r.p.m.	13	B.H.P.
,, 800	,,	18	,,
,, 1,200	,,	27.5	,,
,, 1,600	,,	35	,,

These powers, of course, are not high as compared with modern European practice, but up to the speed mentioned the power curve progresses in a straight line.

The Ideal Carburettor has the following characteristics. The fuel stream is at right angles to the air stream, the former being in a thin film with a constant orifice coefficient. The jet is rapidly adjustable for fuels of different density, and the adjustment can be accurately made by a micrometer screw head; furthermore, the jet can be easily dismounted without the use of tools. The fuel is automatically cut off when the engine stops, and the suction cannot exceed 7 in. of water head.

Fig. 45 shows a longitudinal section through float and mixing chambers. A is the float chamber in which the level of fuel is controlled by an inverted needle valve B and float C, which is provided with a simple locking device D for adjusting level of fuel to compensate for varying density of spirit and wear in the valve or seat. The float chamber is provided with a self-locking and readily detachable cover E. In the base of the float chamber is a large circumferential filter F, which is a light friction fit, and removable by the fingers. The float chamber is cast as an integral part of the bottom cover or jet base G, and is connected to the base of the mixing chamber of the main carburettor casing H, in such a manner that it may be rotated and clamped in that position which is found to be most suitable to any engine. Mounted concentrically at the base of the casing H is the air intake sleeve I and flange L, the former being in two portions, and capable of being rotated to any position. M is the fuel spraying jet, which is of special construction, and is provided with a conical ground seating, permitting its rotation to the most suitable position for observing and setting the graduated micrometer scale. N is the zero scale, which is held by a sunk screw, thus enabling its position to

be adjusted should the jet edges be accidentally damaged. O is the movable scale, permitting the adjustment of the area of the jet to be varied in increments of $\frac{1}{10000}$ of a sq. in. per scale division. The jet orifice consists of an

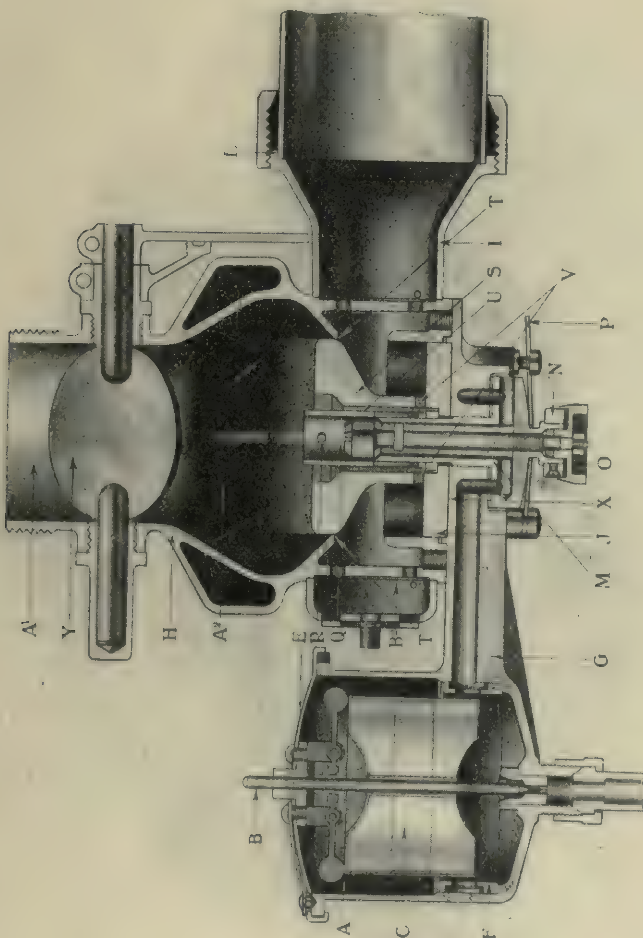

FIG. 45.—Ideal.

annular circumferential opening formed by the jet body, and a movable cap controlled by the small scale O, whereby the width of the annular opening can be varied. The complete jet M can be instantly removed by depressing with a slight side movement the small lever P, which

may be effected with one finger, thereby allowing the jet to drop. The replacing of the jet is as simply and rapidly effected.

Surrounding the said jet M is the fuel sleeve Q, suspended from the cross pin R, which in turn is fixed to

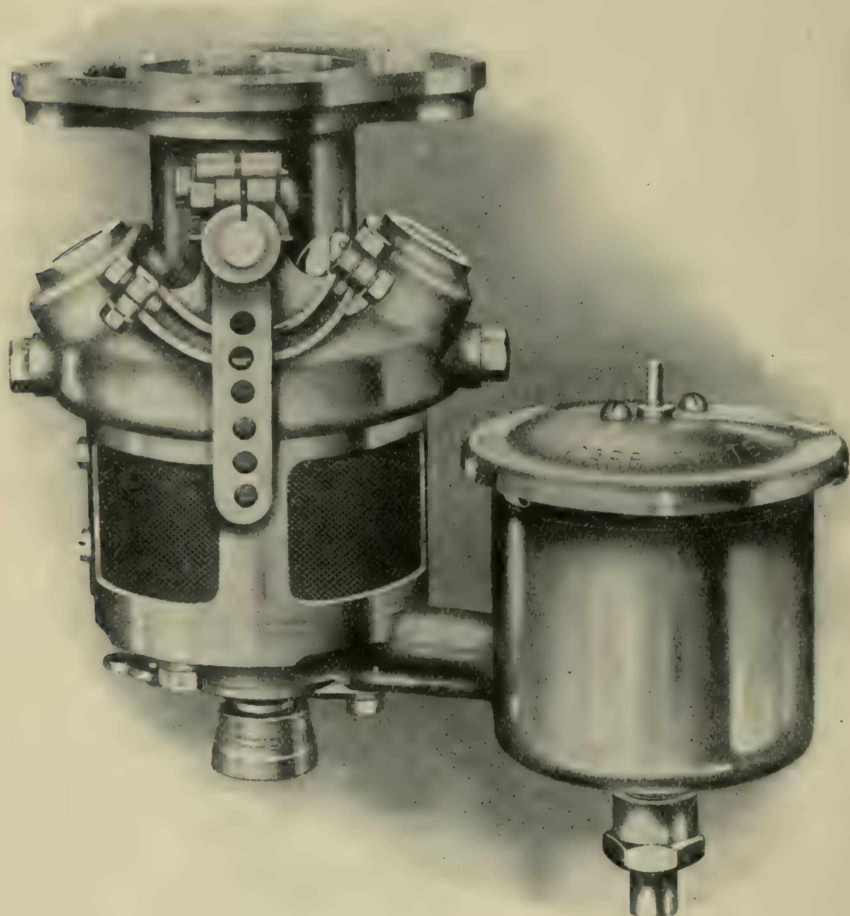

FIG. 46.—Ideal.

the gravity-controlled air sleeve S. The fuel sleeve Q is provided with two triangular slots, the apex of each being slightly below the level of the jet opening when the engine is at rest. As the sleeve Q is raised, an increasing length of the circumferential strip of the jet

is uncovered by the triangular slots. The gravity-controlled air sleeve S is adapted to regulate the air opening formed by the sleeve S and the casing H at the point T. At the lower end of sleeve S, and concentric with jet M and fuel sleeve Q, is a small annular initial air passage U, tapering outward at the top and bottom, and having at its base a number of transverse openings V, communicating with the opening in the air inlet flange L by the air passages W, formed at the base of the main casing H. At the upper end of casing H a cylindrical throttle valve is provided, so constructed that it gives a vacuum-braking effect when the throttle is fully closed, and a filtered air scavenge beyond the full throttle position. The throttle lever is secured to its spindle by a split-coned boss and coned clamping nut, enabling the lever to be clamped in the most convenient position to suit existing control levers with the minimum of trouble. On the throttle valve cover is a circular slot provided with adjustable stops, whereby the air scavenge control may be entirely cut out, or the throttle may be prevented from actually stopping the motor, the stops limiting the travel of lever to accomplish this.

Normally, the gravity-operated air sleeve rests on the bottom cover, the main air passage being closed, and the fuel being entirely cut off by the fuel sleeve. On the throttle being opened a little, and the engine turned slowly by hand, a small volume of air will pass through the passage U into the mixing chamber, in which, owing to the relatively small area of the former, a slight depression or partial vacuum has been produced, causing the air sleeve S and fuel sleeve Q to be upwardly displaced, first uncovering a small strip of the jet outlet sufficient to carburate the small volume of air passing, and then, as the speed of the engine gradually increases, the main air opening T opens up at the same time, proportionately increasing the available jet strip. On a reduction of throttle opening (if the load is unaltered) the partial vacuum in the mixing

chamber will tend to decrease, the air sleeve S being acted on by gravity will move downward, thus reducing the area of the strip T, until the partial vacuum in the mixing chamber is sufficient to support the sleeve, and a reduced volume of gas will pass through the mixing chamber in unit time. The air velocity through the initial annular opening into which the fuel is sprayed is constant under all conditions. The position of the floating sleeve device is not definitely related to either actual throttle position or engine speed alone, but depends entirely on the volume of charge passing to the engine. When the throttle is moved to the air scavenge position, the mixing chamber port A^2 is gradually closed, and the partial vacuum being reduced, the air and fuel sleeves are allowed to return to their normal position, closing the circumferential air inlet, and positively cutting off the fuel at the jet. While the carburettor is essentially of the constant mixture type, up to the full throttle position, there are times when it is desirable that the mixture should be weakened, as when running down a gradient, which is not sufficiently steep to maintain a good average speed by gravity alone. This is obtained by opening the air scavenge a little, which causes the air and fuel sleeves to be lowered slightly, when a smaller volume of carburetted air will pass through the mixing chamber, and be further diluted by the air entering through the air scavenging inlet. This variable mixture effect, which is in conjunction with, but is additional to, the pure air scavenge, makes for economy during average conditions of running, whilst retaining the advantages of a constant mixture for maximum power and controllability under normal working conditions.

Kingston.—The Kingston carburettor possesses certain well-known American features, the first of which is a cork float, and the simple connection between this and the needle valve. Although the cork float is scarcely

in accordance with European ideas, it is really remarkable how well it works. It is, of course, not liable to be completely put out of action under ordinary usage, and it is very cheap. The use of such a float eliminates the necessity for small toggle levers, and it lends itself to easy attachment directly to its lever. The Kingston carburettor has a peculiar jet tube, forming a starting well, situated with its upper orifice slightly above the greatest restriction of the conical choke. A central needle is provided with an adjusting screw and locking device, so that the amount of petrol discharged from the orifice can be varied. Naturally, under normal working conditions, the level of the fuel descends in the starting well to the position of its greatest restriction. When, however, the engine is stopped, a small quantity of petrol can accumulate in the starting well and be ready for restarting the engine. The main air supply, as is somewhat common practice in American carburettors, is led downwards through one leg of a U tube, and, passing upwards in a vertical direction through the carburettor, is led off at right angles through a butterfly throttle. With regard to the principle of the carburettor, the body of the instrument forms a mixing chamber, and the diverging jet orifice, closely situated in a choke tube, should give a very fine spraying effect. Round the upper internal ledge in the mixing chamber a number of balls are placed, somewhat in the manner of the French G. and A. carburettor. These balls form a means for the admission of an additional supply of air when the engine suction is great. A somewhat curious shape of float needle is employed, which may be advisable on account of the large range of movement of the cork float which is used.

The Limit Carburettor, designed and manufactured by Messrs Morgan & Wood of Bristol, was brought into prominence by reason of its having undertaken the first R.A.C. carburettor trial in 1910, and the results shown by

this trial were eminently satisfactory, some of the figures of which are given in Chapter XII. on exhaust gas analyses. This instrument is somewhat on the lines of the Zenith, in that it has a gauged orifice, through which the supply of petrol passes to supplement the usual jet at all periods of running, but it differs from the Zenith type of instrument in that the additional fuel supply is made after total or partial evaporation. This evaporation is said to be a great advantage, in that the requisite amount of fuel is delivered when the suction would be insufficient to operate this quantity of fuel, and in addition there is no accumulation of unevaporated fuel in the carburettor under slow running conditions. Referring to the drawing, a gauged orifice A at the bottom of the limiting tube B is not affected by the suction of the engine, for the tube B is open to the air at the upper end, thus the amount of fuel supplied to the engine from this source is limited by the head of the fuel in the float chamber. The main jet G is fed by fuel in the ordinary way. When the engine is stationary the fuel reaches a level in the limiting tube, which is practically the level of the top of the float, and this level is such that the plug D is surrounded by a film of fuel. When the engine is started, the suction takes effect upon this head of fuel, in addition to the jet G, by way of the orifice L, and the passage F of annular formation, but after the engine has been running a few minutes the excess of fuel available for starting is completely exhausted, and the flow of fuel to the engine is then confined to that through the orifice A and the jet G.

Henceforward a rich mixture for slow running passes up the passage F, and is augmented by a normally weak mixture by way of the choke tube H and the vaporising spiral J from the jet G, and these two mixtures compensate each other and provide a correct mixture. The main jet G is so set that it cannot give a rich mixture at any speed, and the limited supply through the orifice A is set exactly to compensate this mixture to any strength required.

Now the difference between this type of instrument and the Zenith type is that the fuel which passes through the limiting orifice A also is led through an evaporating chamber in which is situated a hollow plug D, and hot water from the engine circulates inside the plug, outside

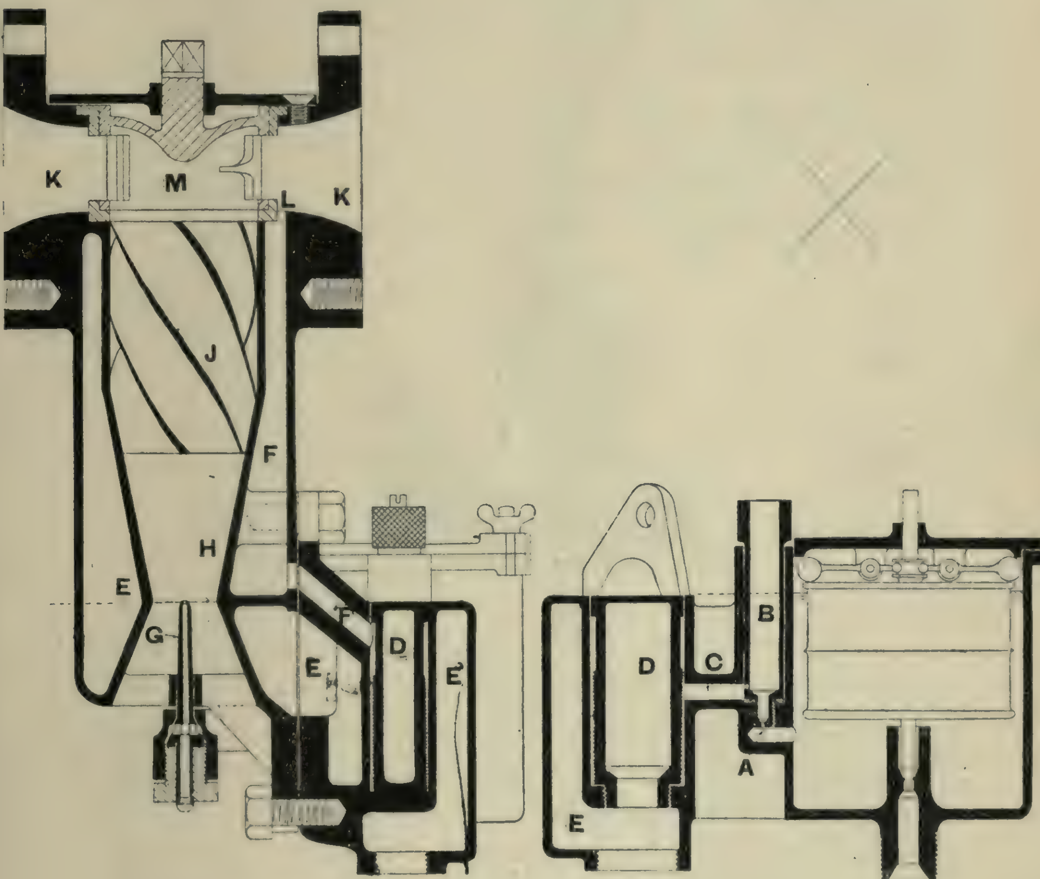

FIG. 47.—Limit Carburettor.

the chamber, and also inside the water jacket of the mixing tube J. The plug D has an additional heating surface formed upon it by means of a long external thread which is cut upon it, and it is plain that the fuel passing through this vaporising chamber is evaporated on its way to the passage F.

Longuemare.—This make of carburettor was one of the very earliest on the market, and is, as its name suggests, of French origin. Since the earlier types, which have been well known to pioneer motorists, the design has not been allowed to stagnate, but has progressed in accordance with modern ideas. The latest type of Longuemare may be said in a great measure to embody two important principles, which appear as original in the Zenith and Claudel types. Considering the throttle first, this is of the barrel type, but, as a difference from the Claudel, the supply of fuel for slow running passes through a small hole on one side of the throttle barrel, and outwards towards the engine through

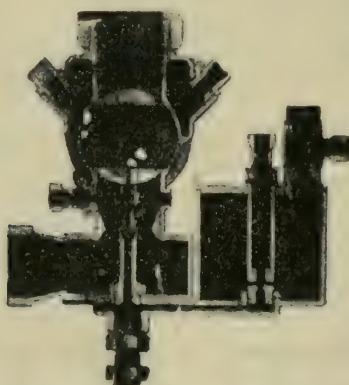

Fig. 48.—Longuemare.

a notch on the other side of the throttle barrel. The jet arrangement in this instrument has several important features which are well worth detail consideration. The presence of a slow running jet immediately beneath the throttle has been referred to, and the supply of fuel to this jet is by means of a concentric tube arrangement, the inner tube supplying petrol through a small jet standing up in a well, to which a regulated air supply is admitted, a thumb-screw and needle valve adjustment being provided for this purpose. In closed throttle position, owing to the throttle valve fitting down on the top of this well, any desired mixture strength can be produced.

At the supply end of this supplementary fuel system

another adjustable needle valve is fitted, but the capacity of this orifice is sufficient for the maximum demand of the engine, and, therefore, when the slow running supply only is in use, the surplus fuel rises up in a reserve well round the fuel regulating needle.

At any particular time, when the throttle is fully opened, this reserve of fuel is free to pass through the main central passage and the main jet in order to give the engine the necessary pick-up when the depression on the carburettor is small. We will now consider the main fuel jet, which in a measure follows the well-known Longuemare pattern. There is an important modification, however, in that the efflux of fuel from the orifices in the main jet is deflected by a small cover plate, so that the fuel stream meets the air stream at right angles. Reverting again to the float chamber and the reserve fuel supply, it will be evident that, as the central tube in the float chamber becomes depleted of fuel by the initial drain upon it when the throttle is fully opened, there will be here a means of a constant air leak through a series of holes in the top of the tube surrounding the needle valve adjustment. In practice, air is allowed to leak through these holes, and to pass downwards through the petrol passage and through the main jet of the carburettor. A claim is made that by allowing a small proportion of air to pass actually with the fuel through the jet orifice, a perfect spraying and intermingling of the fuel with the air is obtained.

The Mayer Carburettor.—This is an American instrument which has been on the market for some years, and its principal feature is that of simplicity. Like the majority of American carburettors, the Mayer is fitted with an extra air valve, and it has also two jets. The air supply is heated. One important feature in connection with this carburettor is the dashpot air control to prevent the air valve fluttering; the air intake pipe is so arranged that both the main and the auxiliary air draw their supply

from the same source. For the sake of easy starting an air throttle is fitted at the carburettor entrance to this air supply, so that the suction upon the jets can be increased when turning the engine by hand. It is claimed that the effect of the dashpot upon the air valve retards its action, so that as the throttle is suddenly opened when it is desired to accelerate the engine, the momentary suction upon the jets is above the normal, and increases the flow of fuel

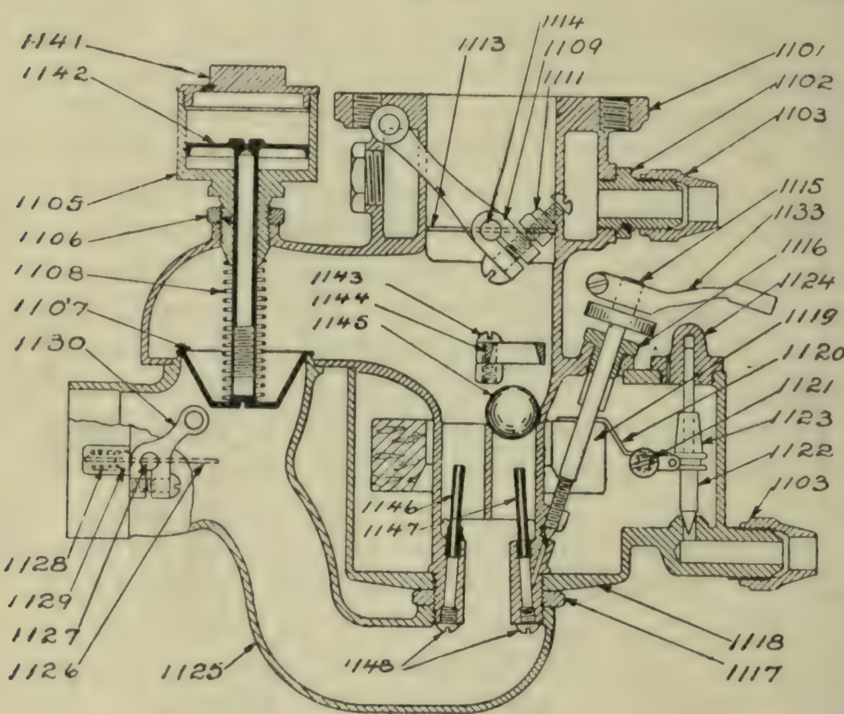

FIG. 49.—Mayer.

before the additional air supply is added. The auxiliary air valve then opens slowly and steadily till it reaches its correct lift, which is governed by the spring.

Referring now to the two jets in the instrument, it will be seen that one is covered by a ball valve and the other has a free outlet, the latter one being the slow running jet. As soon as the engine suction increases to a certain amount the ball valve rises from the second jet and allows

it to come into operation. The principal adjustments in connection with this instrument are made by means of the additional air valve and the needle valve operating the main jet, and by means of these two a sufficiently accurate adjustment can be made for all ordinary purposes.

It will be noticed that the float chamber is of the concentric type, but the method of operating the fuel needle is somewhat unique, and very simple.

Napier.—A simple form of the varying jet orifice is embodied in the Napier design of carburettor for their larger engines. In this instrument the nozzle is of cylindrical form with a flat upper end, and in this end there are two apertures, one consisting of a small hole, for slow running, and the other of a narrow segmented slot. The top of the jet is covered with a cap, also provided with a slot, so arranged that the cap can be rotated when in position and the slots before-mentioned made to register with one another more or less. In this arrangement the cap is connected to the throttle and opened with it. In order to compensate for increased engine speed with a fixed throttle opening, a diaphragm-controlled extra air device is provided, the diaphragm acting upon a cylindrical shutter which uncovers triangular ports.

There are several types of carburettor fitted by the Napier Company to their different sizes of car, and these types vary in principle as well as in dimension. The later model, as fitted to the 15 H.P., is of the two-jet type, there being a slow running jet situated in a conical choke tube, and beside it a jet of similar shape but of larger dimensions, which comes into operation at about one-half the throttle movement.

These jets are situated immediately below the barrel throttle, and the throttle itself being hollow forms a mixing chamber. In it are two apertures: the larger one, of elliptical shape, traverses over the slow running jet, and a circular opening traverses the main jet. It will thus be

seen that the first movement of the throttle enables one jet only to work, and during the second half of the movement the two jets supply the fuel. The control of the mixture to the engine is carried out by means of an opening on the upper part of the throttle barrel, this opening having a

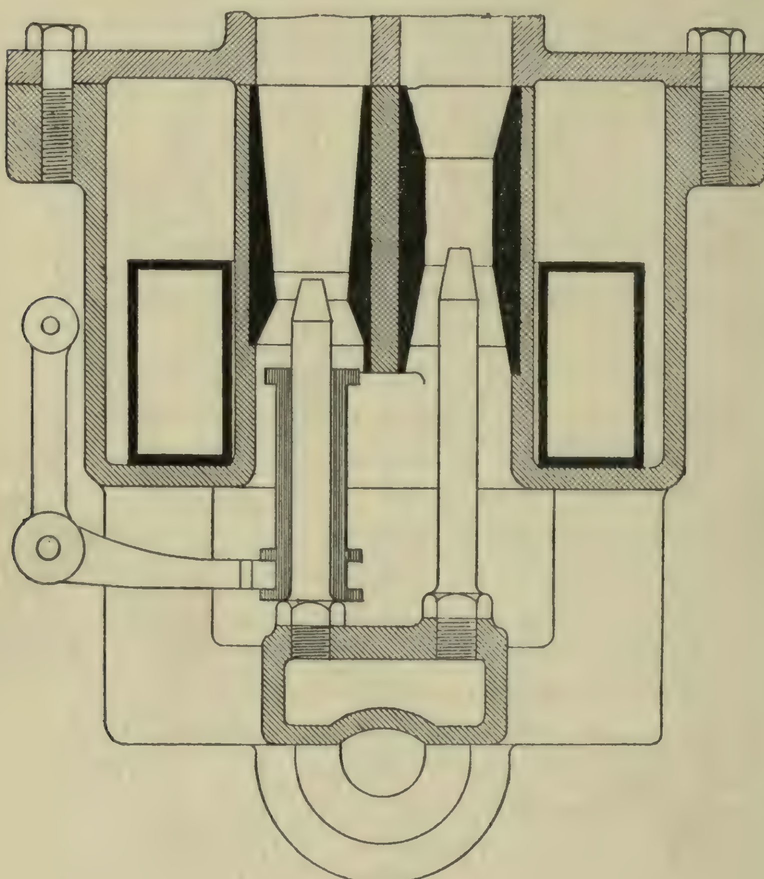

FIG. 50.—Napier.

narrow slit extending at one side of it for the purpose of accurately checking the flow of mixture at low engine speeds. This slit gradually widens out until it gives full throttle opening. The air enters the carburettor in a vertical stream, the lower part of the instrument being provided with a large pan-shaped gauze to exclude foreign

matter in the air. The type of instrument used for the larger models is fitted with a sleeve round one of the jets, mechanically connected so that it can be raised to close the area of the choke tube for slow running. Another type of carburettor fitted to the 45 H.P. Napier has a hydraulically controlled air valve; the pressure of the circulating water acts upon a diaphragm, so that as the engine speed is increased the main air supply is also increased. In this type of instrument it will be seen that the carburation depends in a measure upon the efficiency of the water pump, which would appear to be not altogether satisfactory, as a delicate instrument like a carburettor should either be an independently operated unit or in itself automatic.

The New Miller Carburettor.—This instrument is of American design and manufacture, and comprises several interesting features, the principal of which is the interconnecting of the fuel needle and the extra air device with the throttle. Referring to the figure, it will be seen that there is an internal piston attached to the butterfly throttle which in movement uncovers air ports situated in the mixing chamber of the instrument, and, simultaneously, by means of a lever arrangement, the fuel needle is withdrawn from the orifice in the jet.

This carburettor is designed with a normal air aperture round the fuel nozzle, the auxiliary air being taken through an annular opening, and the proportion between the two is so arranged that the correct amount of vapour is supplied. In order to increase the richness in the mixture the position of the taper needle in the nozzle can be altered from the driver's seat by means of a suitable device, so that the proportions of air always remain unchanged, and the fuel can be increased at will according to weather conditions and grades of fuel.

Another feature of this instrument is that the air ports, when open, allow an unrestricted passage for

the air. The air enters through an annular opening, thus eliminating a deflected charge. The needle and nozzle are in the centre of the instrument, so that an evenly distributed mixture is ensured, and the throttle is attached to the air sleeve giving a positive air opening. Another

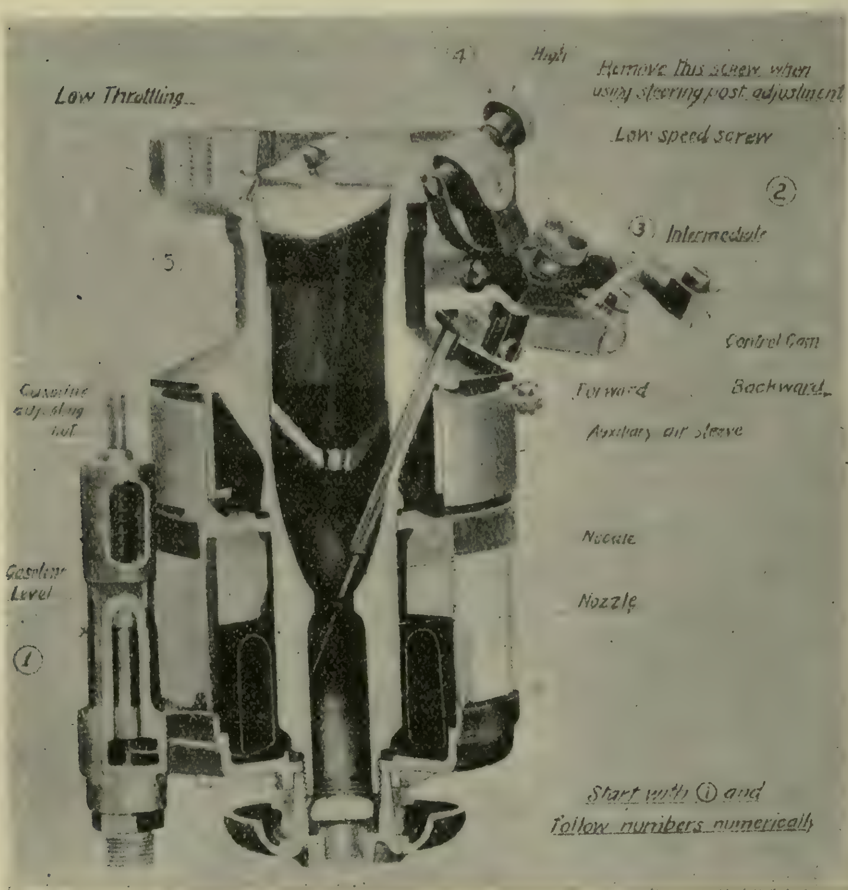

FIG. 51.—New Miller.

important point in connection with this instrument is the mechanical control of the fuel needle, making the whole instrument positive in operation.

It will be noticed that this carburettor is of the concentric type, and a glass float chamber is fitted in the base,

the float chamber itself being maintained in position by means of a screwed cap fitted on to the lower part of the instrument.

It has been mentioned before that the fuel adjustment can be made from the driver's seat, and this is a most important feature, as it is the only adjustment required when the instrument has once been fitted on to the engine.

The needle valve is actuated by a cam mechanism operated by the throttle, and a spring is fitted in the needle valve housing, so that the point at which the needle commences to lift can be adjusted.

Every care is taken in the manufacture of this carburettor, and it certainly appears a free design, with the exception, perhaps, of a multiplicity of moving parts, and the obstruction of the passage of the gas to the carburettor, which exists by reason of the crosshead in the air piston and the linking motion to the butterfly throttle.

Planhard Carburettor.—A radical departure from the usual type of carburettor in a number of ways is made in the improved Planhard carburettor, made by the Planhard Manufacturing Company, 1784 Broadway, New York, and Kokomo, Indiana. The principal differences are in the small number of parts and an entire absence of springs, levers, and cams. This instrument is of the concentric type, the float chamber surrounding the mixing chamber, and is designed in such a way that all joints are in a horizontal plane, and it may be assembled by screwing the central member into the top member.

The proper vaporisation of fuel and its thorough mixing with air to form a correct explosive mixture is well arrived at in the new carburettor of the Planhard Company in its new double concentric air and mixture tube construction. The fuel nozzle is in the centre of the carburettor, and it is entirely surrounded by the fixed or constant air tube. This is contracted at the upper end above the nozzle.

Surrounding this tube, between it and the float chamber wall, is the annular opening through which the auxiliary air is admitted.

This is a most important feature, as the columns of mixture and auxiliary air always travel in the same direction. The auxiliary air surrounds the mixture as it leaves the contracted tube, and acts as an envelope to insulate the mixture from direct contact with the cold walls of the manifold, where it might condense. This surrounding envelope of pure air gradually unites with the inner column of rich mixture until, before reaching the cylinders of the engine, the auxiliary air has thoroughly vaporised fuel in suspension. A dry, rapidly burning mixture is thus produced, and it is claimed that the greatest possible amount of power from a given amount of fuel is obtained.

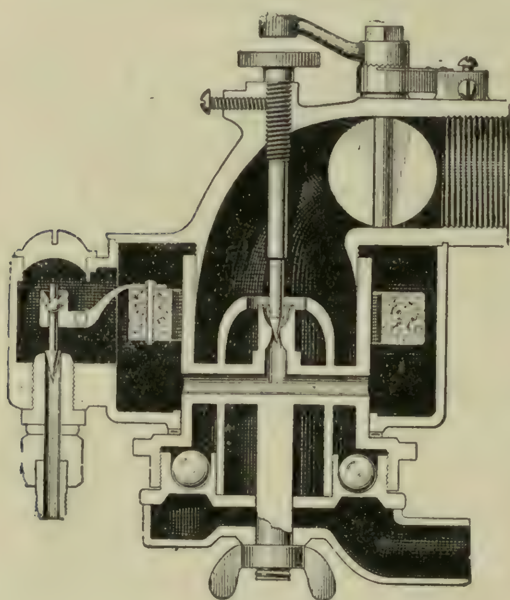

FIG. 52.—Planhard.

The auxiliary air is admitted to the carburettor through a series of ball valves. These are seated in holes in an adjustable screw plate at the bottom of the auxiliary air tube. The ball seats vary in size. The bronze balls are

all of the same size and weight, and are thus lifted from their seats progressively as more auxiliary air is required. The ball on the largest seat is lifted first. These balls act differently from a single auxiliary air valve, which constantly flutters, and, therefore, changes the amount of auxiliary air admitted to a considerable degree from the correct amount. The ball valves used in the Planhard carburettor each lift a distance about equal to that of the lift of a single auxiliary air valve, but as these balls lift progressively, their total travel amounts to six or eight times that of a single valve for the same function. The balls do not flutter, and on account of their range of action they are not delicately poised, and, therefore, give for varying engine speeds a uniform amount of auxiliary air.

The spray nozzle is cup-shaped, and when the motor is standing idle this fills with fuel to within a short distance of the top, and acts as a priming device, thereby making the starting of the motor easy. The float chamber is provided with a flooding device and a vent. The air pan at the bottom of the carburettor is secured by a wing nut, which also serves for clamping the adjustable auxiliary ball plate, which is knurled on its periphery, so that the lift of the auxiliary ball valves may be quickly and easily adjusted, whereupon the plate is locked by the wing nut.

The Planhard carburettor is of exceedingly robust and simple construction, and embodies in one unit not only several standard features of carburettor construction, but such special ones named above. One noticeable feature is the very simple method by which the float actuates the needle valve, also the removable needle valve seating.

Polyrhoe.—The Polyrhoe is of the constant suction automatic type, and is so arranged that the row of jets is situated slightly above the level of the petrol in the float chamber. The difference of pressure under which the instrument works is just sufficient to cause the petrol to flow from those jets which are in operation, and

to spray it effectively. The operation of the instrument is as follows: In the throat of the instrument a piston works against the action of a large spring, the total range of working being only a portion of the total range of the spring, thus errors due to spring action are practically eliminated. As the demand of the engine increases the piston recedes, carrying with it a tongue piece which travels

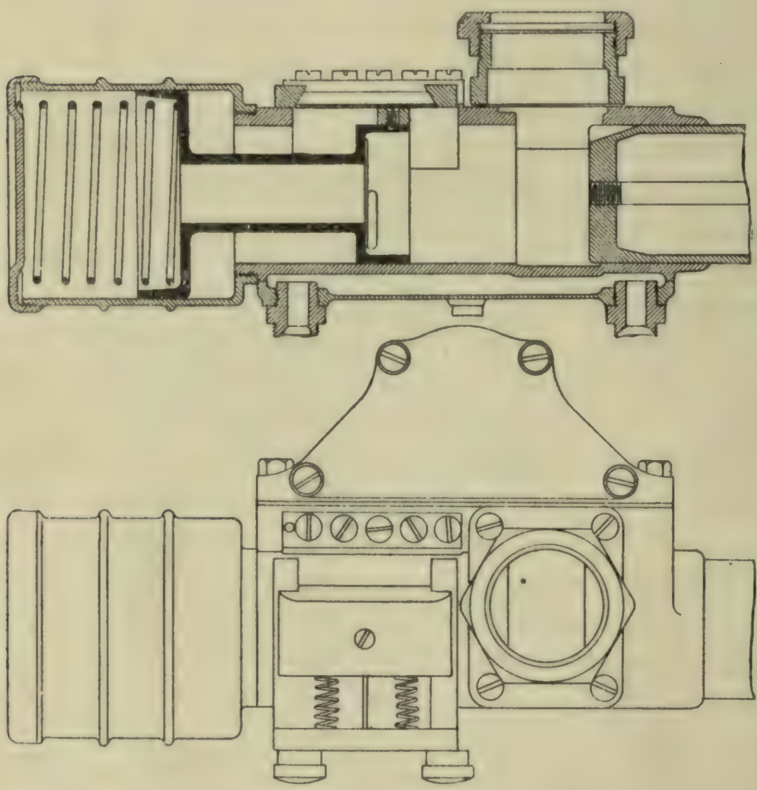

FIG. 53.—Polyrhoe.

over the jet orifices in such a manner that all those orifices situated above the air inlet orifice are directly acted upon by the suction produced. The remaining orifices communicate with the surrounding atmosphere, but being out of line of direct suction, no petrol is caused to flow from them. It will thus be seen that for any one position of the air piston and tongue piece there is a direct relation

between the area of the rectangular air slot and the combined area of the numerous petrol orifices.

Now, in order to alter or vary this relation, the air orifice only requires attention, and for that purpose a slide is provided, whose movement is in a direction at right angles to the direction of movement of the air piston.

This slide is actuated by means of a Bowden wire from a lever controlled by the driver ; thus the proportions of the mixture can be altered at will by the driver at any time whilst the car is running. It has been shown that for slow speed running and starting up a mixture somewhat richer than the normal is required ; this is on account of the fact that incomplete combustion usually occurs under such conditions. To comply with this necessity, it is only necessary in the Polyrhoe carburettor to arrange the air slide so that some of the jets are open when the air slide is shut, and that, at small openings of the air slide, there are always that same number of petrol jets operative in excess of the correct number. As the air opening increases, the ratio of these extra jets to the total is so small that the effect of their operation becomes negligible. A circular or drilled jet orifice is extremely difficult to manufacture accurately in small sizes, a drilled hole of such dimensions is seldom round, and a series of such holes cannot be guaranteed to be of exactly the same size. For this reason the Polyrhoe jets consist of a number of slits in thin metallic foil clamped together in five layers. The slots in the various layers are staggered, so that the effect in actual working is that of a continuous and uniform jet opening. The disposition of these jets is such that the incoming fuel becomes intimately mixed with the air, and a perfectly uniform charge results.

As practically the whole of the evaporation of the fuel in this carburettor takes place at the air throat, the necessary heat need only be supplied to the carburettor body, and for this purpose a hot-water jacket is fitted. However, this instrument can be more easily started from cold than

many others, as, on account of the adjustable air slide, more fuel in proportion to the air can be allowed to pass to the engine in the initial stages when the heat is not sufficient, nor the temperature high enough to vaporise the heavier fractions of the fuel. When, however, normal working temperature is reached, the air slide can be opened and an economy in fuel effected. We all know the difficulty in running a correctly adjusted carburettor for the first few minutes when cold, and such a difficulty can be overcome when an accurately marked position for the normal adjustments is provided. By these means the instrument can be thrown out of true adjustment for the first few minutes as shown.

It is interesting to note the very small percentage of carbon monoxide in the exhaust gases of an engine tested with this carburettor, for it never exceeded 0.2 with the engine loaded, and 0.8 with the engine running light.

During these tests the proportion of CO_2 varied from 13.4 per cent. to 13.8 per cent. when loaded, and from 13.2 to 13.5 per cent. when light, the consumption of spirit of 0.760 sp. gr. being at the rate of 45 ton miles per gallon on the track at a speed of 20 miles per hour.

The "Rayfield" Carburettor, manufactured by the Findeisen & Kropf Mfg. Co. of Chicago, has been very successful in America, especially in connection with racing cars.

The principles of operation of this instrument are that it combines both the automatic and mechanical means of control, and that the needle valve is lifted, and the mechanical air valve raised proportionately as the throttle is opened. In addition, an automatic air valve supplies such air as is not admitted by the mechanical air openings.

At low speed, both the fixed and mechanical valves are completely shut off, giving a very small volume of air, which passes through a choke tube at the side of the fuel

nozzle, and consequently the motor can be readily throttled down.

At high speed, however, all the air openings are in operation, thus giving a very free access of air to the mixing chamber, with the result that the depression in this chamber is smaller than that usually obtained.

The adjustment for low speed running is obtained by rotating a screw which raises or lowers the needle valve to give the required mixture, while the high speed adjust-

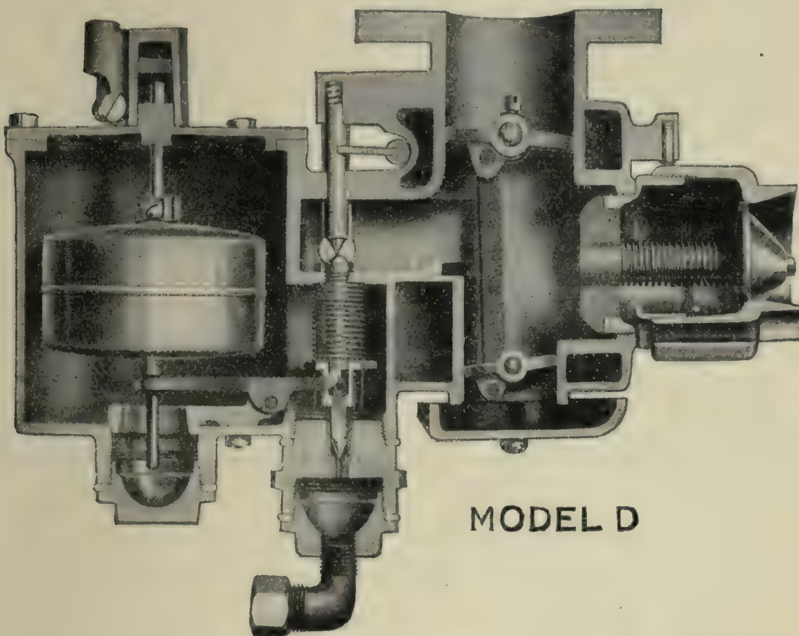

FIG. 54.—Rayfield.

ment moves a cam forward or backward, giving more or less lift to the needle valve as the throttle is opened. In addition to these two adjustments there is one for the air valve for intermediate speed.

It will be noticed that the Rayfield carburettor belongs to that class in which the flow of fuel from a single nozzle is controlled by a needle valve in connection with the throttle, but in addition to the usual interconnection one sees that the main air entrance is closed by an additional

throttle which is linked to the main throttle in the mixing chamber.

The movable needle is held towards its seat by a spring of the spiral type placed above it, and is operated by a small arm interconnected with the throttle mechanism. The link motion operating the valves can be adjusted, so that the correct proportions of the air and fuel can be arrived at.

The Rayfield carburettor has a float chamber of unusually large dimension, the float being of metal, operating through a lever upon the needle valve, below which is placed a large strainer. Admittance of fuel to the mixing chamber is through the centre of the nozzle, which is opened and closed by the needle, the lower end of this nozzle communicating with the fuel chamber by means of a series of holes.

It will be noted that in the action of this instrument direct mechanical means are principally employed, and it is necessary to pay attention to three distinct adjustments in order to effect proper regulation, but when once made require no further attention. This is naturally a somewhat difficult matter for the ordinary motorist to undertake, and to the European mind it appears unnecessarily complicated.

There is still one further difficulty or departure from what is now standard practice, in that the air for carburation does not all pass the jet, in fact only a small portion of it comes in any direct line between the jet orifice and the throttle valve.

Schebler (Fig. 55).—Here we have one of the simplest arrangements, which, moreover, works in a satisfactory manner. Not that this carburettor has any particular claims from a scientific point of view, but in its country of origin fuel consumption is of minor importance. The instrument is made in several forms, but the principle is the same—a single fuel jet, with variable suction up to a certain point, then an unstability of affairs as a

spring-actuated air valve is allowed to open. There is a distinction, however, in this carburettor as compared with the older types of well-known spring-controlled air valve instruments, in that the extra air is admitted on the atmospheric side of the jet, and not to the carburetted air stream between jet and throttle.

In the Schebler carburettor a small air aperture is provided of $\frac{3}{8}$ in. to $\frac{1}{2}$ in. diameter, say at right angles to the

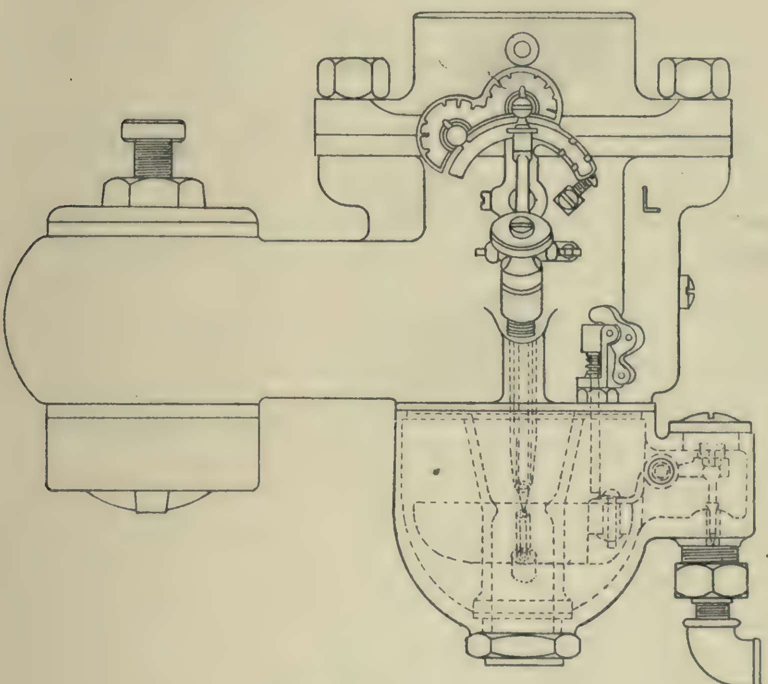

FIG. 55.—Schebler.

main mixture pipe, and in the bend of the carburettor a single jet is screwed, say at an angle of 45°. The jet may be situated in a vertical position in the bottom of the carburettor with a small air aperture round it. As the engine speed increases the air velocity increases in the ordinary way until the depression inside the instrument reaches a certain value. At that time a spring-actuated air valve opens and admits an additional supply of air,

which is allowed to cross the jet, and from that moment it is difficult to state exactly what are the conditions of pressure and air velocity inside the instrument. These conditions will depend upon the tension of the spring and the shape of the air passage, and may be varied at the will of the driver, but he has of necessity to descend from his seat and make any adjustments directly by hand. A small flap is usually provided to close the whole of the air intake for starting. The throttle is of the butterfly type.

As this American carburettor has been much improved by means of the addition of an adjustable and variable fuel nozzle, it will be as well to give it further consideration. The Schebler carburettor is primarily fitted with an inclined nozzle, entering the aperture of which is a needle with a very steep taper. This needle is directly operated by the throttle, and its movement can be regulated at three different points. The actuating mechanism consists of a bell-crank lever, which works with a partially rotary motion, so that a small projecting arm attached to the fuel needle traverses a cam-shaped path. For adjusting the slow running position the needle itself can be moved upwards or downwards in the jet orifice by means of a milled head, and when this adjustment is made, the throttle can be opened. The projecting arm on the fuel needle then traverses the cam-shaped path, and the needle itself is raised by the small spring shown, the amount of lift being regulated by the contour of the path on which a small roller runs. This path is a piece of flexible metal, and it is adjustable at its middle and remote positions by means of two quick pitch screws fitted with dials. In order, therefore, to give a greater or less effective area to the jet at any point it is only necessary to rotate the dial fingers in one direction or the other. These fuel adjustments, it will be noted, depend entirely upon throttle opening, and have no relation to the demand of the engine at any time. It is, therefore, necessary to combine some form of air regulator, and this is done by

the adoption of a spring-actuated air valve, through which the whole of the air passes. The Schebler carburettor, like several other American types, uses a leather valve for this purpose, and this valve is first set by making it seat lightly when the throttle is almost closed and the engine running slowly. Obviously such an arrangement, though convenient in some respects, cannot be considered in the same class as a modern European carburettor as regards automaticity of action, too much dependence being made upon the action of the air valve. The carburettor, however, is fairly easy to adjust from time to time.

The Latest Type.—The new Schebler model "O" differs from all previous Schebler carburettors, in that two spraying jets or nozzles are used, one being the main jet located in the Venturi air passage, which is concentric with the float chamber, and the second jet which is fitted higher up in the wall of the carburettor. The secondary jet is under the control of a plunger valve, which is raised from its seat by the suction of the engine, and only comes into operation after an engine speed of about 800 revs. per min.

The operation of the instrument is as follows: After a speed of 400 revs. per min. has been obtained, the auxiliary air valve commences to open, and is in operation in speeds of from 400 to 800 revs. per min., and above this latter figure the auxiliary jet comes into play, this jet being situated in a small pocket between the operating valve and its seating, when the former is raised by the engine suction.

The air for this auxiliary mixing chamber enters through a port in the casting leading to the outside atmosphere.

This instrument is hot-water jacketed, and is fitted with an air shutter to facilitate starting.

Scott-Robinson.—The Scott-Robinson (Fig. 56) constant suction carburettor has been on the market for some

years, and though at first sight it may appear somewhat similar to other instruments discussed, yet it embodies several interesting features. In the first place, although the jet orifice is controlled by a modulating pin, the flow is not directly acted upon by the air stream, but there must of necessity be a certain amount of lag in the action of the instrument due to indirect suction. An important feature of this carburettor is the perfection of the dashpot, with

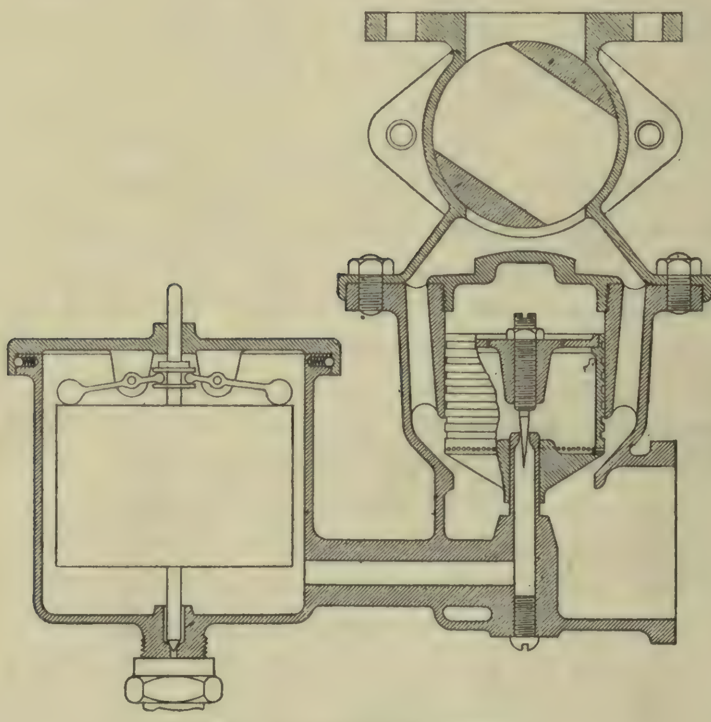

FIG. 56.—Scott-Robinson.

which all constant suction instruments must be provided to ensure effective working, and in the Scott-Robinson this adjunct is probably the best we have come across. Considering the carburettor in detail, the action depends upon a moving part controlling air and fuel flow, and operating between gravity direct on the one hand and engine suction on the other.

The moving part comprises a hollow piston, which also

acts as a dashpot, and contains within its interior a modulating pin. This pin can be adjusted as regards vertical direction by means of a screw and locknut in the head of the piston. The fuel, issuing from the orifice under the influence of engine suction, is precipitated within the floating piston, and trickles out through a number of small holes drilled round its lower edge.

This edge forms a valve seating, and is normally, when out of action, located upon a conical portion of the carburettor casing. The whole of the fuel thus passes from inside the floating element, through the series of holes, and meets the air stream passing through the annulus round the outside of the floating element. An even distribution of fuel in a fine spray is thus obtained, and in this instrument the whole of the incoming air passes in direct contact with the fuel.

The carburetted air passes directly upwards round the casing of the dashpot and through a throttle of the rotating drum type. As the demand of the engine increases, the floating element rises, and is permitted to do so by the dashpot, a small air-leak hole being provided in the head of the floating piston to allow the air in the dashpot to escape into the piston during this process.

It will be noticed in this instrument that it is necessary to do a certain amount of dismantling in order to make the preliminary adjustments, as the floating element must be removed for this purpose.

The modulating pin is, however, safely housed away from all possibility of outside interference, and is not in direct contact with any impurities which there may be in the air stream. A small refinement will be noticed in the method of fixing the lid of the float chamber, and one which might be more generally adopted. This consists of a number of metal balls, spring-actuated, which grip in a groove in the float chamber lid, and allow the lid to be removed without the use of tools.

The "Scot" Carburettor embodies several unusual features in its design, principally that of having eight jets instead of the usual number.

In the illustration only two of these jets are shown, one of them being at A. All the eight choke tubes are formed

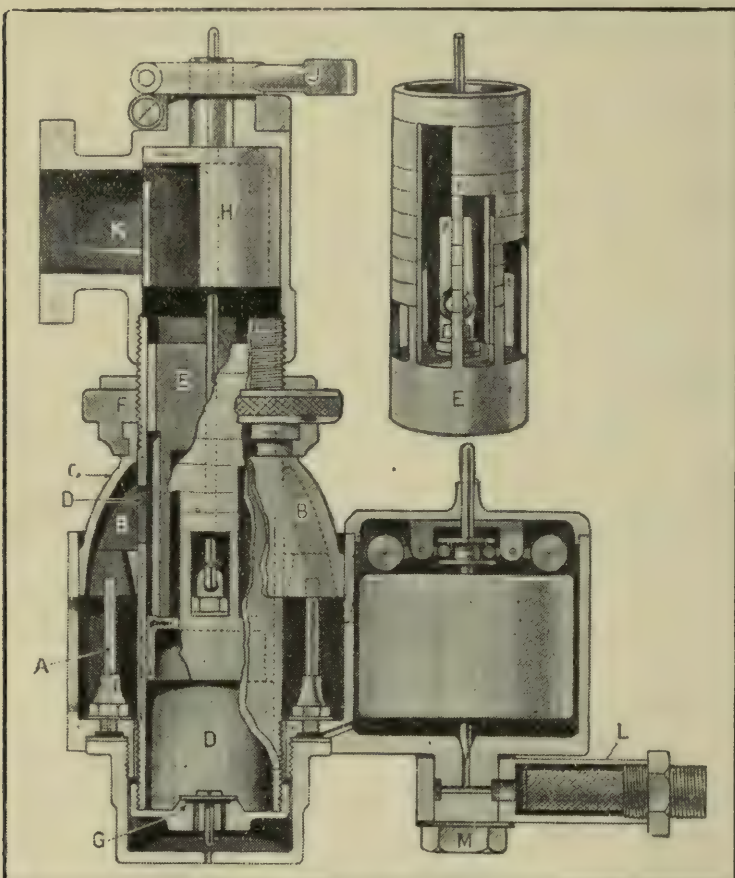

FIG. 57.—Scot.

in a sliding cone-shaped piece C, the mixture passages B being continued upwards and passing into the mixing chamber through the ports formed in the main tubular body D of the carburettor. Within this body is an automatic piston valve, which is shown separately in the illustration, this valve being formed with slots of eight

different lengths, and it is normally at the bottom of its travel in the tubular casing D.

In this position one only of the slots is in line with a port in the casing, and thus only one jet is operated upon.

It is claimed that this single jet is sufficient to run an ordinary engine up to a speed of about 400 revs. per min. when light, but as soon as a load comes upon it and the throttle opens, the additional suction of the engine lifts the automatic valve or piston so that the various slots in turn come into operation, and so cause the fuel jets to be acted upon. By this means the fuel and air supplies are regulated automatically by the requirements of the engine and the throttle movement.

The dashpot action for the piston is provided by enclosing the space marked D so as to form an air buffer and prevent a rapid downward descent of the piston, and a small valve G is placed in the foot of this space so as to admit air when the piston is required to lift. Thus the air damper only acts in one direction, and it will be noticed that the choke tubes are of taper section, and by means of an adjustment, provided in the form of a knurled nut F, the latter can be raised to any desired extent, so that the effect of an adjustable choke tube is obtained for each jet.

In this instrument passages are provided communicating between the jet chamber and the float chamber, these being formed within the cover of the float chamber and the walls of the jet chamber, the effect being to equalise the pressure between the two chambers. When the pressure in the vicinity of the jet chamber is much lowered by the suction of the engine, depression of pressure also occurs in the float chamber, thus in a manner neutralising the tendency for the jets to discharge an excess of fuel.

The "Senspray" Carburettor acts on an entirely different principle to other instruments on the market. It is common knowledge, that if a current of air is blown

through a nozzle of a small bore held at right angles to the mouth of another similar nozzle, whose lower end is immersed in some liquid, the liquid is sucked up the jet and projected forward in the form of a fine spray. The successful application of the principle has hitherto been confined to such articles as "scent sprays," "artists' fixing sprays," and to the instrument known among medical men as a

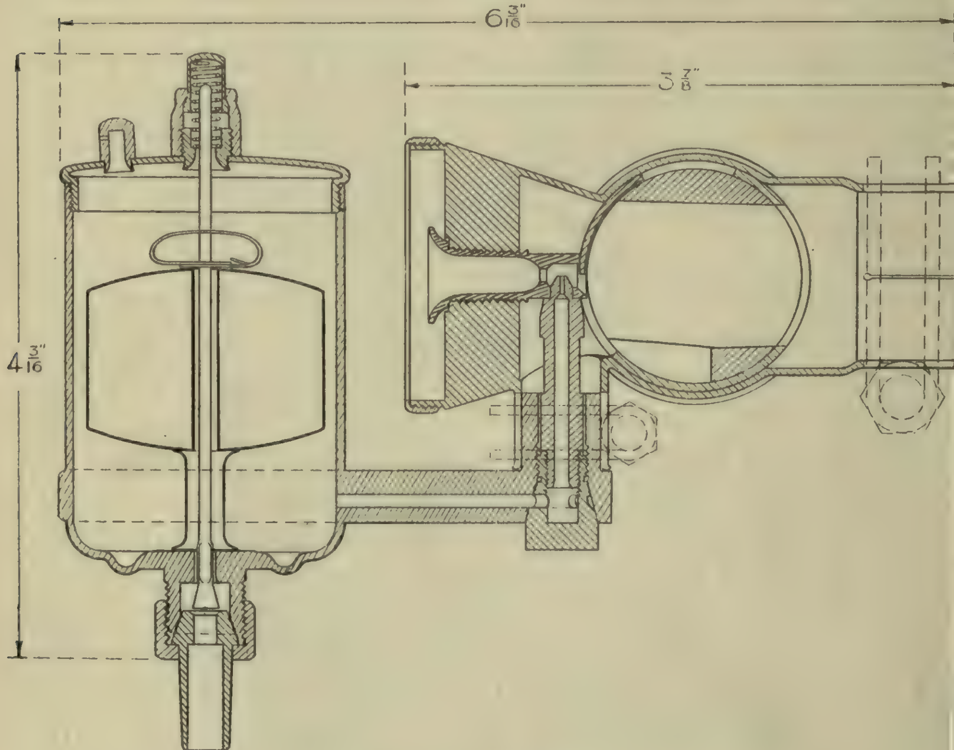

FIG. 58.—Senspray.

"nebuliser," which is used for spraying the throat and nose with certain liquids of a healing or disinfectant nature. It is obvious that the principle lends itself particularly well for the purpose of perfectly atomising petrol, or other fuel, for internal combustion engines.

Reference to the sectional diagram of the instrument will show how the principle has been adopted in practice. It will be seen that with the air shutter in its lowest or

closed position, and the throttle only slightly open, the velocity of the air through the vaporiser is increased, and this gives the strong pulling at slow engine speeds, which is accomplished in some instruments by means of a pilot (or small) jet, in a separate small choke tube, without the attendant disadvantages of the liability of a very small jet to become choked.

A small volume of air is drawn by the engine suction through the vaporiser or spraying nozzle at a high rate of speed, directly over the top of the petrol jet, which forcibly draws the petrol out of the jet and sprays it into the mixing chamber in the form of a fine mist. At the same time the air necessary to form the explosive mixture is admitted straight in at the back of the carburettor, and a perfectly atomised firing charge is thus obtained.

The instrument is of the well-known "straight-through" type, giving at full throttle a clear way through into the engine, and is semi-automatic in action ; that is to say, that except for starting, and to enable the engine to pick up when it slows down on a severe gradient, the air lever can be left open most of the time, and the driving done on the throttle lever only.

The semi-automatic action of the carburettor is due to the cylindrical rotary type of throttle valve used. It may be termed a "Duplex Valve," as, to a certain extent, it acts in a two-fold manner both as an air and throttle valve. Indeed, the use of this type of valve renders it an easy matter to make the instrument entirely automatic, or one lever-controlled, as having determined the largest jet that a particular engine will take with full air and throttle, the slot which is cut in the throttle to admit the air necessary to complete the mixture at small throttle openings is then opened out to give a good mixture at all points of the throttle opening. The air valve can then be dispensed with ; but the makers prefer not to do this, as even when it is "tuned" to the engine in the way described above, it is exceedingly difficult, if not impossible, to counteract the

variation in atmosphere, variations in the gravity of the fuel used, and variations in engine speed (and hence suction on the jet), at a given opening of the throttle due to the varying gradients of the road. The makers believe that these difficulties can only be met by the use of a separate air control, which in the case of the Senspray is conveniently incorporated in the handle-bar control (for motor cycles).

The throttle is supported in ample bearings at each side, and as all air admitted to the instrument passes first through a large gauze dust cap (which effectively excludes all grit), there is no tendency for the valve to stick.

The air shutter works round the periphery of the throttle valve, being pivoted on the throttle spindle-bearing, and the return of both valves is secured in a very ingenious manner by the action of one strong rust-proof clock-spring.

The float chamber, which is adjustable at either side of the instrument, follows the standard practice, and although a "tickler" is fitted to the cap, there is in practice no necessity for its use.

The jet is instantly accessible without disturbing any other part of the instrument, and as the base (or jet holder) is conical in shape, a sound metal to metal petrol-tight joint is assured.

Solex.—The Solex (Fig. 59) is of French origin and manufacture, of the two-jet type, but it differs very considerably from other two-jet instruments which have previously been dealt with. The most interesting feature of the Solex is the arrangement of the slow running jet, and the means provided for introducing the mixture to the engine side of the throttle when this jet is in operation. It will be noticed that the central tube in the float chamber around which the float is situated is fitted at the top with the slow running jet, and the petrol is drawn up this tube through the hole near its base shown in the diagram.

Some of the air supply for slow running enters the small ball valve at the top of the float chamber, the air passing downwards and across the top of the supplementary jet. The mixture then passes through the passage towards the choke tube, and thence vertically upward through the throttle trunnion, and to that part of the carburettor situated between the two halves of the butterfly throttle valve. In order to start up, therefore, the throttle must

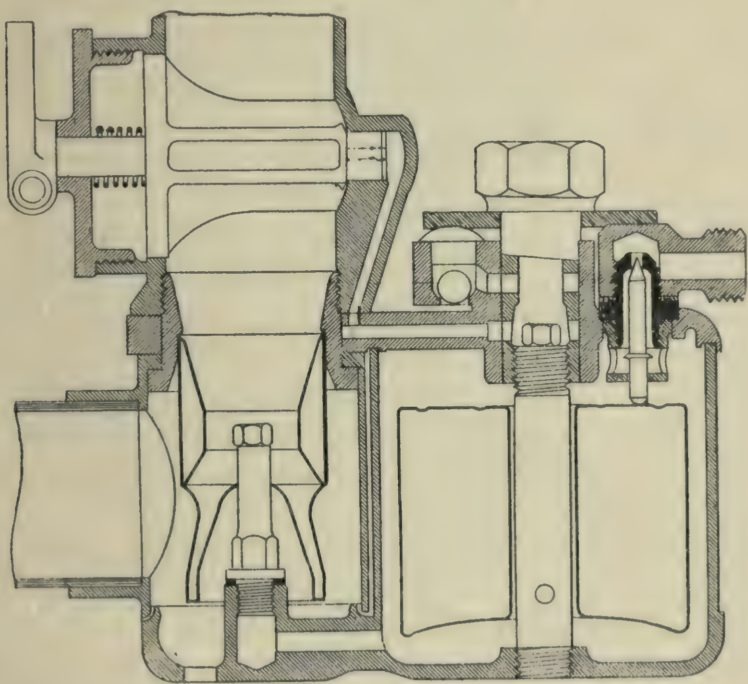

FIG. 59.—Solex.

be put in its closed position. The object of the ball is to reduce the suction over the smaller jet when the throttle is nearly closed. The actual passage of the mixture for slow running is regulated by means of moving the throttle bodily in the direction of its axis, and the end of the throttle where the mixture enters can be drawn sideways, thus forming a valve. If the auxiliary jet is obviously on the large side, the throttle can be adjusted laterally to give the necessary amount of mixture, and then a smaller

slow running jet can be fitted of such a size that the engine will run slowly without missing fire. The larger the auxiliary jet, the better will be the pick-up. In addition to these two adjustments there are two more main adjustments for power, these being the main jet and the choke tube. There is thus in this carburettor ample scope for anyone who is that way inclined to make numerous adjustments. Fortunately, however, these adjustments, when once made, are not easily capable of derangement, as they are mostly of a fixed nature. The design for the carburettor lends itself to easy dismantling, and the one large nut situated above the float chamber holds the two main portions of the instrument together. Furthermore, the large washer beneath it holds in position both the petrol union and the tap over the ball valve. It will thus be seen that when this nut is slacked back the carburettor can be taken to pieces for adjustment, if the petrol needle valve is held upon its seat by any convenient means. This valve is normally pressed up to its seat directly by the top of the float, and no toggles or levers are necessary. The carburettor is not water-jacketed, and a hot-air supply is recommended.

In the latest form of Solex a composite jet is fitted, which allows a certain amount of air to pass through a tortuous passage and mix with the issuing stream of fuel.

Such an arrangement increases the atomising effect, particularly at high engine speeds.

Stewart Precision.—One of the latest successful carburettors overcomes any difficulties of the adjustment of petrol level, for in the Stewart "Precision" (Fig. 60) this level is some 3 in. below the actual orifice through which fuel issues to the mixing chamber.

The Stewart Precision carburettor is of the constant suction type, and immediately a normal condition of working is arrived at the difference of pressure is of the order of 9 to 10 in. of water-head. The main working

element consists of a gun-metal valve supported in the air stream, and provided with a small central tube dipping at its lower end into the float chamber, its upper end being level with the top of the valve.

For some distance along the upper length of this

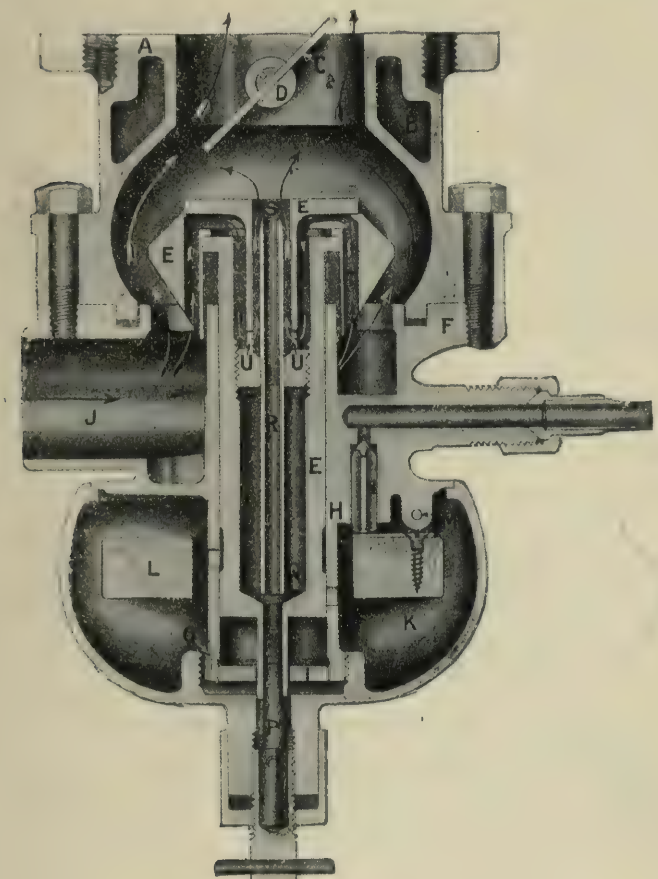

FIG. 60.—Stewart Precision.

tube is an annulus, communicating by means of a number of holes with the lower or atmospheric side of the valve.

The air passes through the valve and up the annulus, drawing with it petrol through the centre tube.

The main hole through the valve head is $\frac{3}{8}$ in. diameter,

whilst the inside diameter of the petrol tube is $\frac{1}{8}$ in., and it terminates about $\frac{1}{8}$ in. from the level of the top of the valve.

This small tube extends downwards to a petrol well, formed within the valve stem, and the valve stem itself is provided with a lower extension tube $\frac{5}{8}$ in. long, and $\frac{1}{4}$ in. diameter outside in the $1\frac{1}{4}$-in. carburettor.

It is this lower extension which is used for regulating the supply of petrol to the engine, and its method of operation is as follows :—

When the floating valve controlling the air and petrol supply is on its seat, sufficient air passes through the valve by way of the eight holes admitting air from below, and through the valve head to the mixing chamber by way of the central $\frac{3}{8}$-in. hole. This air is concentrated, therefore, round the orifice of the central tube, thus enabling a sufficiently high suction effect to be obtained when the engine is cranked round by hand at starting.

Continuing the consideration of the $1\frac{1}{4}$-in. type, which type, by the way, is most suitable for engines of the 3-litre capacity, and supposing that the engine is properly tight, the valve will remain upon its seat until a speed of 130 r.p.m. is reached, when the cylinders are 100 per cent. full of mixture.

Naturally, when the throttle is closed and an attenuated charge is admitted, the engine speed can be increased up to somewhere about 200 r.p.m. or more, depending upon throttle tightness and absence of leakage before the valve commences to rise.

The admission of petrol through the valve by means of the lower projecting tube is controlled by a taper pin, provided with a suitable adjustment passing through the lower part of the float chamber.

When the valve is on its seat the taper pin is lowered, so that the annulus round it permits of the correct flow of petrol to suit the amount of air passing at the minimum slow running, and in slow running positions the increase of

petrol flow is produced by the increased suction as more air passes through the valve.

When the point of equilibrium is arrived at, the valve commences to lift off its seat, and air passes round the outside of it as well as through its centre.

From this point it is important that the rate of change of area of the petrol annulus should be the same in proportion as the rate of change of air annulus, making due allowance for friction and viscosity in each case.

These rates of change depend upon the shapes of the passages, and there is, of course, a constant and a variable in both cases. In carrying out numerous experiments with this instrument many important and interesting points have come to light, and particularly the influence of the shapes and sizes of the taper pins upon the resulting petrol flow.

In the first place, it will be noted that the regulating device is always submerged in petrol and is not, as in the majority of other carburettors, an intermediary between petrol on the one side and air on the other side. It does not, therefore, function as a spraying device. We have, however, to take into account the effect of hydraulic friction, but not capillarity. As the suction is constant at all speeds after the valve has commenced to lift, one would expect to get a flow of liquid proportional in magnitude to the area of the annulus, neglecting the difference in the friction of the orifice between the limits of working. This frictional effect is somewhat curious, for one must bear in mind that when the annulus is small, the ratio of the length of annulus to its net area is greater than when the valve has lifted, and when a greater volume per unit of time is passing.

Sthenos.—The Sthenos carburettor (Fig. 61) is one of the oldest carburettors in existence, and was in all probability the first instrument in which a Venturi choke tube was used, the early type being fitted with a jet tube

terminating in a mitre-seated valve, which could be adjusted by means of a small screw passing down the centre of the jet, fitted with a nut at its outer extremity. The modern Sthenos carburettor naturally differs considerably from the early type, its two principal points of divergence being in the adoption of a double jet—the small one for slow running only—and the use of a resistance screw in the fuel passage to the main jet. First considering the pilot jet, a

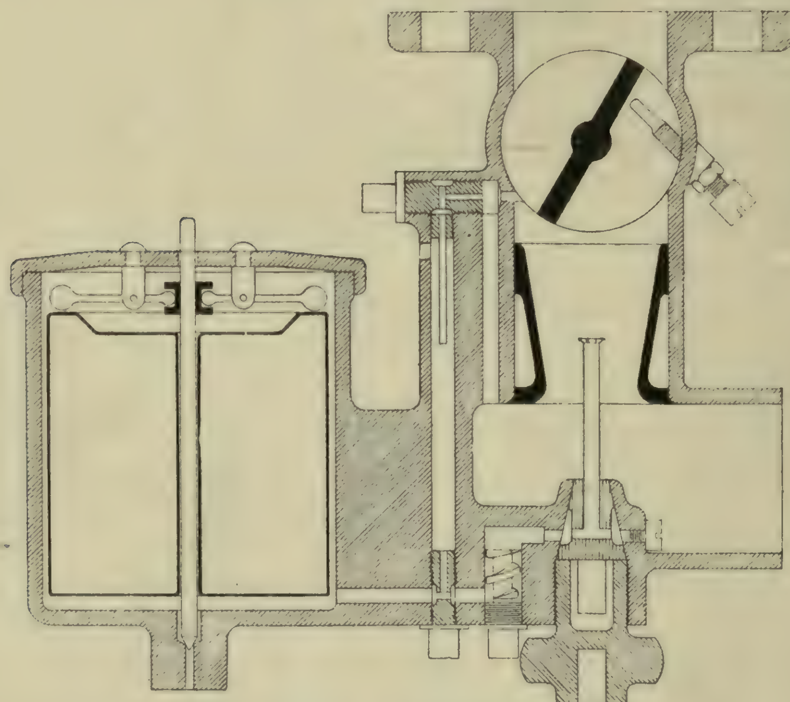

FIG. 61.—Sthenos.

small orifice is fitted at the base of the fuel passage, which at its upper end communicates with the throttle chamber at the engine side of the throttle when the latter is in its closed position. This petrol uptake is open to the atmosphere, but a small internal fuel pipe is provided through which the petrol can pass on its way to a second small orifice which allows only sufficient fuel to pass through it to run the engine slowly. A small air pipe is provided to admit

sufficient air to the supplementary fuel orifice for slow running, and this fuel and air supply become inoperative as soon as the throttle is opened. Now, with regard to the main supply, the resistance screw in the fuel passage has already been referred to, and in a previous chapter it has been pointed out that the shape of these screws could not be calculated theoretically, but could only be arrived at by practical methods. The presence of this screw in the Sthenos carburettor is probably the only instance of the continuance of this type of regulation in modern practice, and no doubt the lengthy experience of the manufacturers of this instrument has enabled them to produce a screw which gives satisfactory results. The damping out of an excessive fuel supply under high depression is also assisted in the diminution of fuel head as the demand of the engine increases. It will be noticed that the supplementary jet is cut out of action altogether as soon as the fuel level falls below the extremity of the small internal pipe which supplies the supplementary jet. The modern Sthenos carburettor has certain features of other well-known types with regard to its adjustment, and it particularly calls to mind the Zenith in several of these respects.

S.U.—Important amongst the constant suction types of carburettors is the S.U. (Fig. 62), adopted extensively by the Wolseley Company. This carburettor is of the modulating pin type, but in distinction to the instrument already described, the pin is exposed to the air flow, and its range of working is much larger than that of the Stewart.

The main feature of the S.U. carburettor is the combination of air choke with a variable jet orifice, and it is so operated that the air stream is concentrated at right angles to the fuel stream, the air velocity being always of constant magnitude. The operation of the instrument is by means of a single moving part comprising a piston, fitted with a modulating pin, and working against the action of gravity, tending to lower the piston, and the suction of

the engine tending to raise it. As distinct from many types of constant suction instruments, the S.U. moving portion is set at an angle of 45° to the vertical, and there are thus variable forces coming into play when the instrument is set in a fore and aft position on a car. These variations may be due to the position of a car at any time

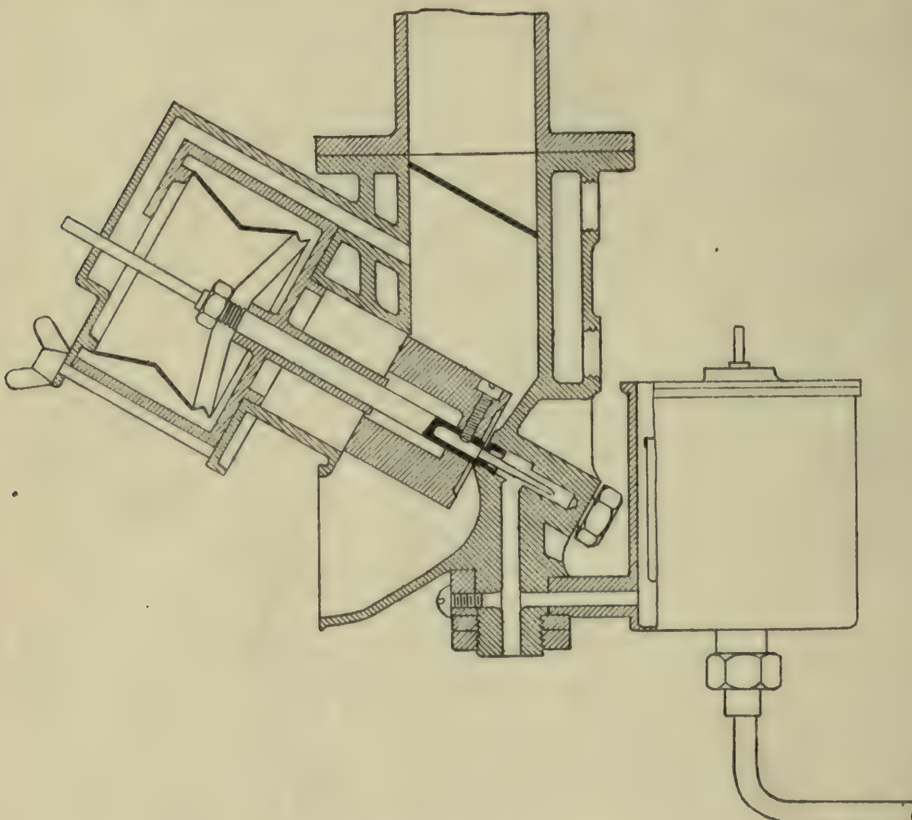

FIG. 62.—S.U.

upon a hill, as the vertical component of the action of gravity in a downward direction will vary in magnitude with the angle of the instrument. For this reason the Wolseley Company fit the S.U. carburettor transversely, thus obviating one difficulty as long as the car remains on a flat road, and does not heel over on one side or the other. Piston tightness, and consequently friction of the moving

part, is eliminated by the use of a leather bellows attached to the operating piston at one end, and to the carburettor casing at the other end, there being a communicating passage between the interior of the bellows and the portion of the mixing chamber on the air side of the throttle.

Thus the suction below the throttle at any time is communicated to the operating piston, causing it to move upwards until the normal intensity of suction is reached. The air piston being directly connected to the throttle piston causes the latter, together with the modulating pin, to work in unison, and to open the air inlet in direct ratio to piston linear movement, but the modulating pin can be formed as desired to suit any particular engine.

We have already seen that with pins, having a uniform taper, the flow of fuel is not exactly proportional to the linear movement of the modulating pin. As a result of experiment, therefore, the pin must be formed to give a correct mixture of fuel to air at any position of the pin and the air piston.

As distinct from some other types of constant suction instruments, the S.U. is arranged so that the whole volume of air used by the engine is carried across the fuel stream, through what is virtually a choke tube of varying dimensions, and it must be remembered that the air velocity through this tube is constant at all times. In order to give sufficient concentration and suitable shape for the air stream at low demands, the surface surrounding the jet is formed into a ridge with the jet let flush into it. The lower part of the choking piston is also formed concave, so that, when this piston is at its lowest position, an effective area or constant leak of one-twentieth of a square inch is provided. Referring to Fig. 62, one or two points will be evident which call for some comment.

The method of adjustment for the pin leaves something to be desired, as, in order to raise or lower the position of the modulating pin relatively to the choke piston, it is necessary to open up the carburettor and release the small

screw which holds the pin in position. This adjustment cannot, therefore, be made whilst the engine is running. It is only fair to state, however, that the pin adjustment is an extremely easy and rapid operation once it has been removed from the carburettor, together with the bellows. This carburettor requires a hot-water jacket, and, like other constant suction instruments, difficulty may be experienced when starting cold until the normal working temperature has been reached. One might expect to find trouble in connection with the leather air bellows, but apparently this part of the instrument does not suffer from undue wear and tear in actual practice.

A great point in favour of this carburettor is its small and compact form, and the smallness of the obstruction which it offers to the air flow. For high efficiency work it should, therefore, give very fine results. The throttle employed is of the ordinary butterfly pattern.

The Stromberg Carburettor.—The Stromberg carburettor is made in several models, the "A" and "B" type being of the single jet, while the "C" is a double jet design—"B" being of the concentric float construction for small engines, whilst "A" and "C" are of the usual Stromberg pattern, with the float chamber at one side; the float chamber being made of a glass tube, which is one of the distinctive features of the Stromberg carburettor.

Some of these instruments are water-jacketed around the Venturi tube chamber, whilst other types are hot-air heated.

The latest Stromberg two-jet carburettor has, in addition to the main central jet, a subsidiary jet fitted slightly to one side, in a horizontal passage between the mixing chamber and the auxiliary air valve. This jet has an adjustable needle valve regulation (not shown).

The auxiliary Venturi tube, which is now fitted over the main jet, is threaded into the carburettor body. This part is so grooved that an opening extends round the Venturi,

The side of this opening towards the float chamber opens through the main body of the carburettor to the atmosphere, and the other side opens in the fuel pipe leading to the auxiliary nozzle at a point above the fuel level. Its operation is as follows: The primary nozzle in the Venturi supplies all the fuel necessary for slow speed running, but as the motor speed increases the suction on

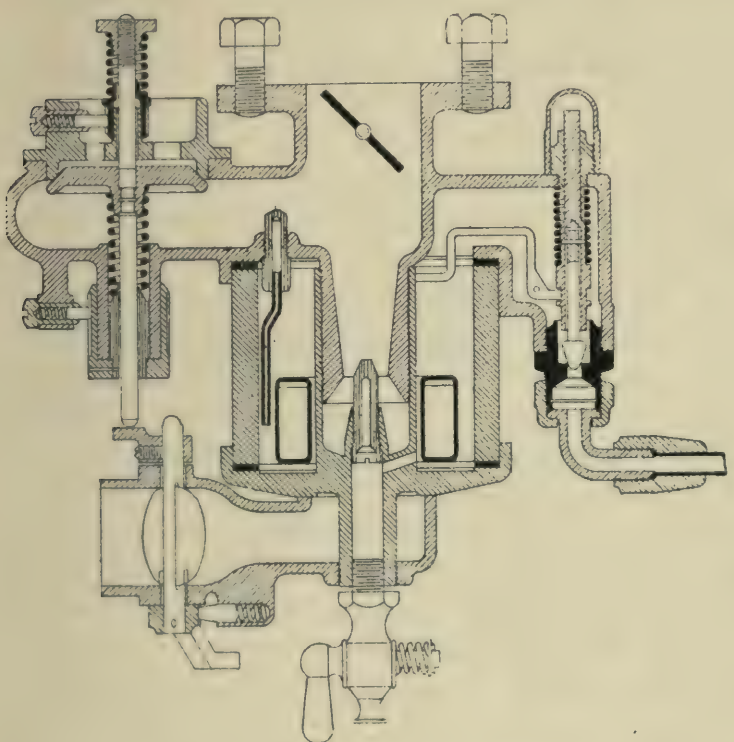

FIG. 63.—Stromberg (earlier type).

the auxiliary fuel nozzle also increases, but no fuel issues from this nozzle until the suction of the motor becomes greater than the capacity of the leakage hole connected with the atmosphere to the groove around the Venturi.

After this point is reached the fuel flows through the supplementary nozzle, its flow increasing or decreasing with the motor's speed.

Model "B" is so arranged that the needle operating

the auxiliary jet is controlled by the auxiliary air valve. This valve, being a new design, works in a chamber surrounded by a sleeve which can be operated from the dash. This sleeve fixes the size of the air opening for the valve, the hollow valve stem carrying two pistons operating in a dashpot so as to control the quality of the mixture issuing from the jet, depending whether the sleeve air opening is exposed to a lesser or greater extent.

Trier and Martin.—Probably one of the best known multiple jet carburettors in this country was the T. and M. (Fig. 64), the principle of which has already been alluded to. This instrument is of the right-angled type, its main features being the combination of three or more fuel jets, with a suitably formed horizontal sliding sleeve throttle, so arranged that the mixture openings vary with the uncovering of one or more of the jets. By the use of three jets in series, where the air stream passes across the tops of the jets at right angles, there is of necessity a certain irregularity of fuel operation which is far more pronounced than in types such as the Polyrhoe, where the number of jets is large. In the T. and M. carburettor, however, this effect was reduced by forming small wells round each jet, situated closely to one another, so that the tube or sleeve which travels across the tops of these wells spreads out, as it were, its blanking effect over a larger area than it would do were it simply to pass across the jet orifices.

The throttle sleeve, with its extension piece, being hollow, allows the mixture of fuel and air to pass through its centre, and form in reality a mixing chamber, the intensity of the air stream being regulated by means of a rotary air shutter situated at the inlet end of the instrument. The main air supply to the choke tube is conical in form, and is provided with a spring-closed valve in the centre of the rotating air shutter, so that at high engine speeds an additional supply of air is allowed to enter. With

regard to the jets, these are three in number in the small sizes of carburettors, whilst in the larger sizes there may be as many as four or five. Over the top of the jets is a removable plate, through which they can be inspected or withdrawn, and in the side of the jet chamber small holes are drilled so as to allow a certain quantity of air to be drawn directly through the jet pockets, thus creating a fine spray of fuel. In order to obtain slow running, a by-pass is provided, which draws air at a high velocity across

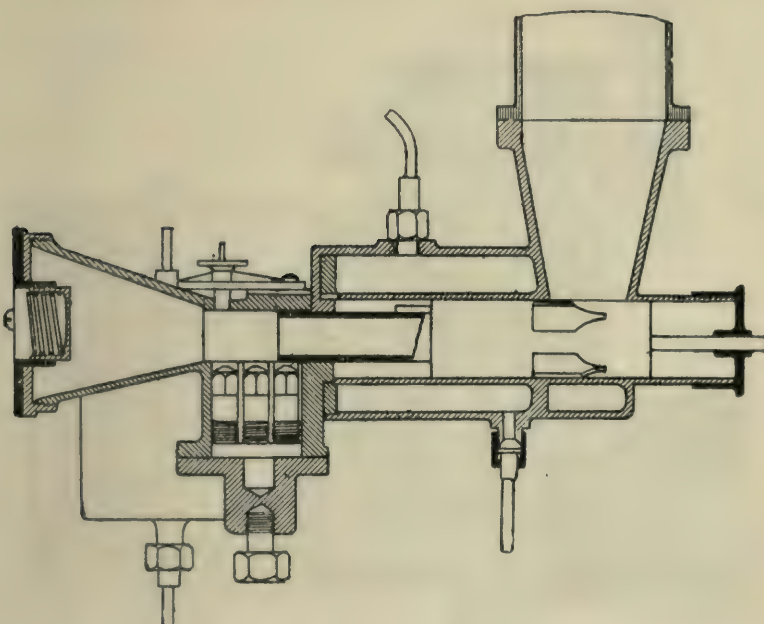

FIG. 64.—Trier and Martin.

the second jet when the throttle is closed, and the mixture is delivered to the engine side of the throttle by means of a small tube passing through the water jacket. This jacket embraces the body of the carburettor round the air throttle casing, and the slots in the air throttle are so shaped as to give a gradual opening.

Vapour.—The vapour carburettor (Fig. 65) has recently made its appearance. This particular instrument is so

arranged that the petrol well or tube over the jet communicates with a small hole passing out at the engine side of the throttle, and another small air hole is provided so that, in the initial stages of starting up, the petrol is drawn from the well and up the small tube more or less in bulk.

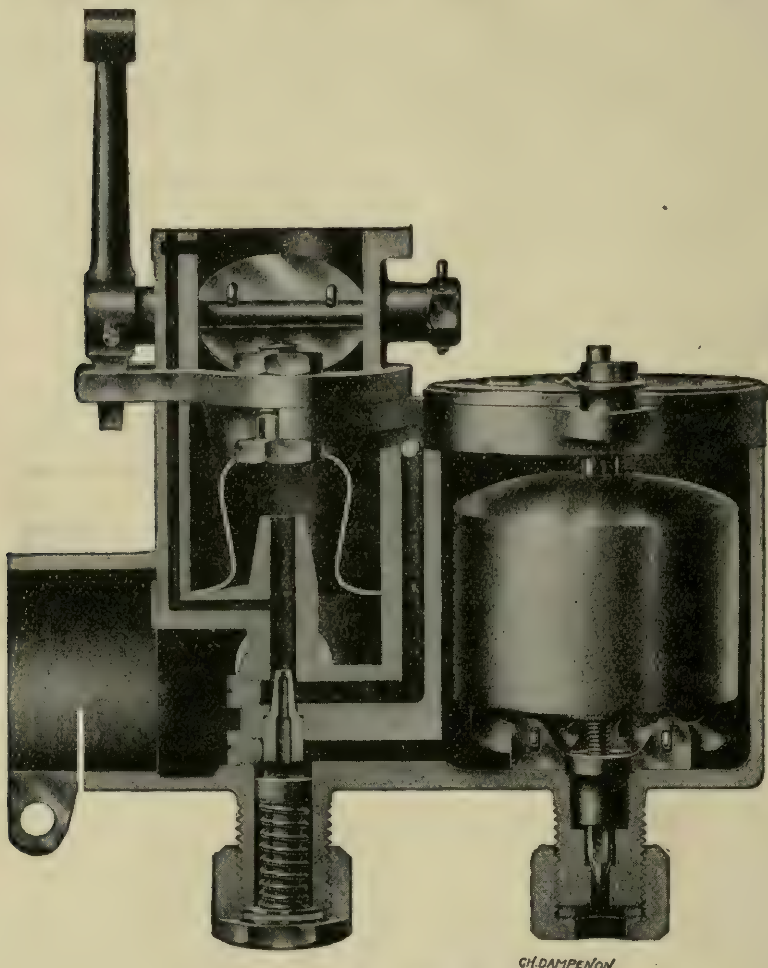

FIG. 65.—Vapour.

As soon as the well is exhausted the jet is no longer submerged, and a stream of air at high velocity issues with the petrol from the small hole situated in the top of the starting well, the air passing across the top of the petrol jet and helping to spray the petrol up the tube and into

the carburettor body. This instrument is provided with a choke tube, and the two adjustments consist in the replacement of this choke tube or of the jet as may be desired.

In arriving at the size of the various parts of this carburettor the diameter of the choke tube is the basis from which the calculations are made—or from which experiments originate. It is the practice of the makers to adopt the well-known formula based upon cylinder diameter and compression ratio, which is as follows :—

$$d = \frac{D}{11}\sqrt{R}$$

where d = the diameter of the choke tube.

D = the diameter of the cylinder in the same units.

R = the compression ratio.

This formula takes no account of stroke.

Ware.—The Ware carburettor (Fig. 66) is probably best known in connection with the Straker-Squire car, upon which it has appeared as a standard fitting for some years past. Although its general appearance has altered from time to time, its general principle has remained as follows: The carburettor jet proper consists of a small nozzle submerged in the fuel in the float chamber; in the earlier type this nozzle was situated at the end of a vertical tube, provided with a central adjustment needle, terminating at the top in a milled-headed screw. In the top of this tube two holes were drilled, allowing a certain amount of air to enter and pass down the tube, meeting the petrol as the latter passed upwards to the engine. In order to arrange this adjustment conveniently it was necessary for the air stream to enter the carburettor horizontally, and through a horizontal throttle. In the later arrangement this conical horizontal throttle has been dispensed with, and a more convenient form of plate throttle and choking tube employed. It will be seen that the concentric petrol and air tubes have been retained, but without the means of adjustment; this latter is eliminated by employing fixed

orifices and a double system of operation. Supposing, now, that the plate throttle is shut, there will be a considerable depression at the engine side of the throttle, and the means

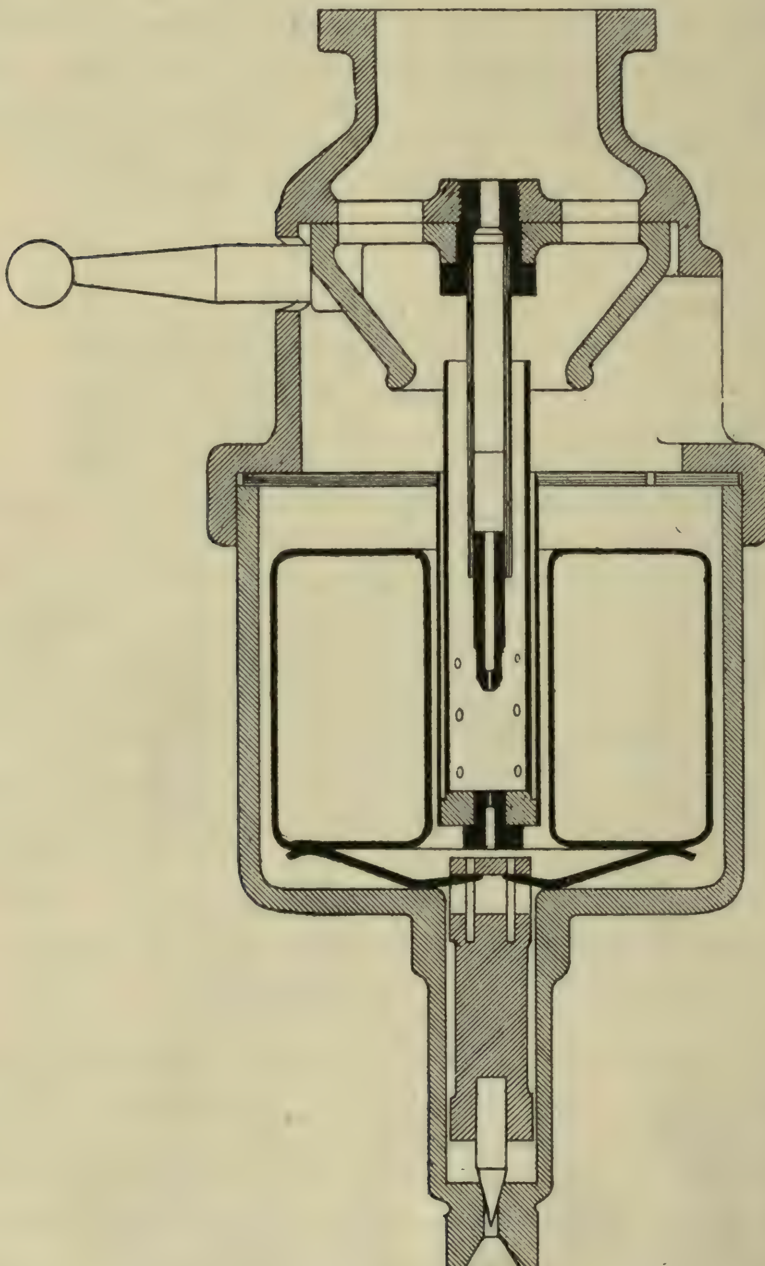

FIG. 66.—Ware.

of air inlet will be down one of the vertical tubes and upwards through the centre tube, carrying the petrol with it. A maximum of suction will, therefore, be experienced at the end of the central petrol nozzle. Now, when the throttle is open and the engine demand is great, the point of maximum depression in the system will be at the throat of the choke tube. The action will, therefore, be as follows: Air will enter the outer annulus between the two larger vertical tubes, and will pass through the petrol by way of the perforations in the second tube, and will issue, together with a certain amount of petrol, up the annulus between the second tube and the central tube. When the suction is a maximum a certain amount of petrol will also pass up the central tube, its flow being governed by the size of the jet orifice at the lower extremity of that tube. There is thus a combination of jet and surface carburation taking place, and this combination can be adjusted to give very satisfactory results under all conditions of working, and it may be added that in practice quite an abnormal "pick-up" is obtained with good fuel economy.

Welsh.—The Welsh carburettor (Fig. 67) is a form of multi-jet instrument, having a downward air-flow through two small vertical tubes situated in the float chamber. These tubes are provided with a number of apertures of various sizes in each, corresponding with a series of figures stamped on their upper edge. The tubes are lightly held in position, and can be rotated or moved at will whilst the engine is running, so as to bring any desired aperture into working position. In the base of the instrument a rotary throttle is fixed, and divided into two compartments; the first portion of the throttle movement communicates with one of the small tubes, and on opening the throttle further the second tube is also brought into operation. These inner tubes, by means of their perforations, communicate with the float chamber, and the downward stream of air draws a certain quantity of fuel from

the float chamber in accordance with the velocity of air passing and the size of the hole employed. This instrument is simple and compact, but the holes through which the fuel passes should be carefully made in order to ensure satisfactory working. The stream of mixture issues in a direction at right angles to the downward air-flow, and

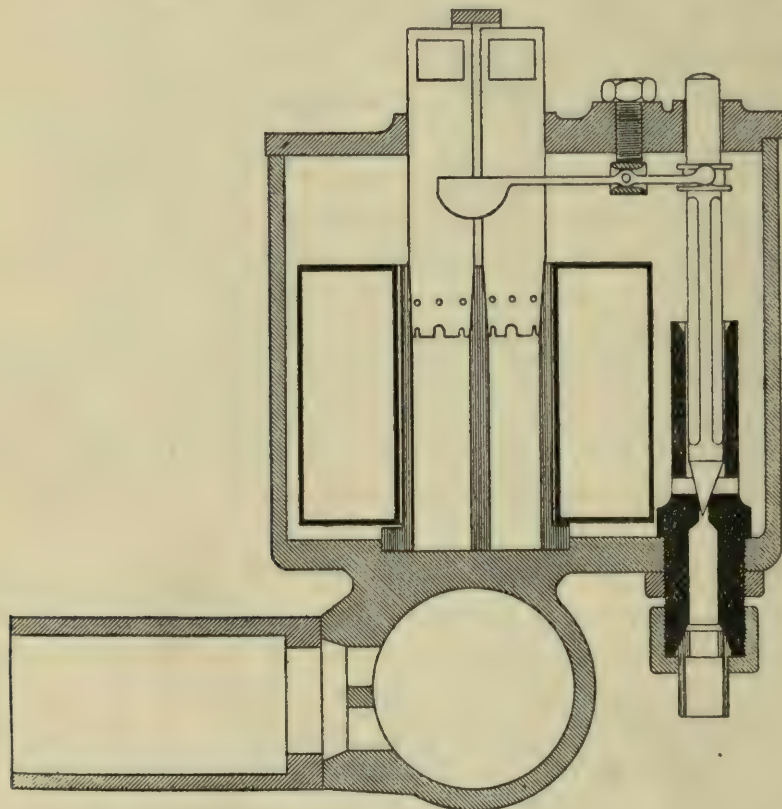

FIG. 67.—Welsh.

the inlet of petrol to the float chamber is controlled by a long vertical needle and a lever with an adjustable fulcrum. This adjustment is necessitated in order to maintain the petrol level on a level with the apertures in the jet sleeve, otherwise either flooding might occur or the instrument might refuse to work on account of these apertures being above the petrol level. This carburettor is not jacketed.

White and Poppe. — The double adjustment is simplified in carburettors of the White and Poppe type, in which the jet consists of a fixed and rotating part, the fuel holes being drilled eccentrically, so that when one part rotates relatively to the other the effective aperture becomes increased or diminished in size according to the degree of rotation. In the White and Poppe carburettor a jet cap

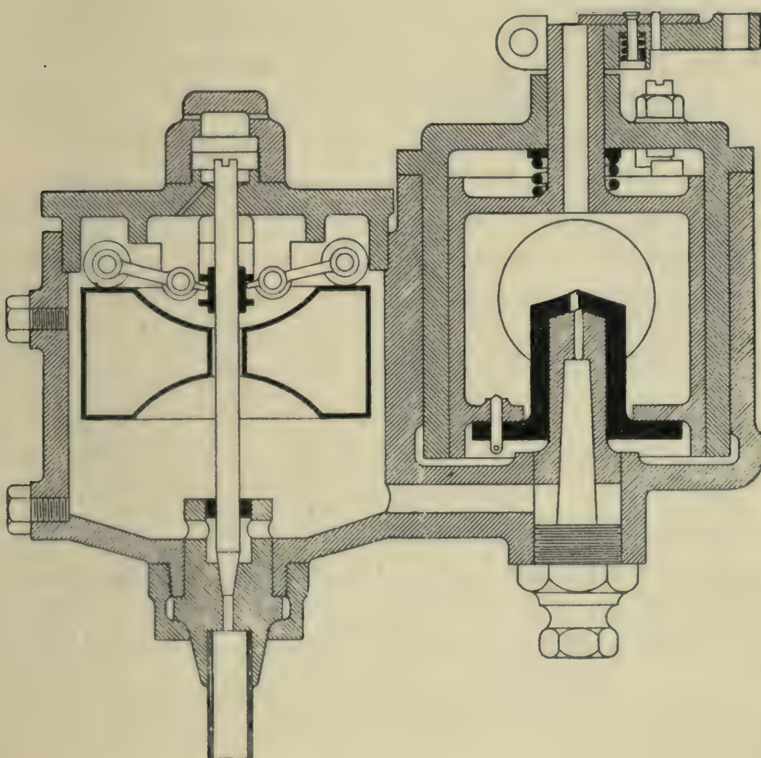

Fig. 68.—White and Poppe.

is combined with a rotary throttle, which acts upon the incoming air and the outgoing mixture simultaneously; such an arrangement being, so to speak, "mechanically automatic."

The White and Poppe carburettor (Fig. 68), to which brief references have been made from time to time with regard to the means of varying the jet orifice, has other

important features which will bear further discussion. It has been found, for instance, as the result of numerous experiments, that the most suitable area of petrol orifice for any particular carburettor is fixed definitely, and that the ratio of area of the petrol orifice to that of the air orifice is 1 to 500. It will thus be seen that when the two holes in the jet which become concentric at full throttle opening are of the same size, a definite relation exists at all throttle positions between the air and petrol orifices. However, if one of these holes be reamered out slightly larger, a certain lead can be given to the petrol orifice, the effect of which is similar to that obtained in other instruments which have already been under discussion.

The latest type White and Poppe carburettor is fitted with a constant air-leak over the top of the jet orifice, the area of which can be fixed at any desired value. In place of the plain hole of the earlier instruments, a cam-shaped plate is fitted in the later models as a cover to the constant air-leak hole, and this plate can be located in any of twelve different positions, thus giving a wide range of adjustment.

The throttle of the White and Poppe is of the ordinary barrel type, but it is of much larger dimensions than, for instance, the throttle of the Claudel, which latter almost completely surrounds the jet. As a result the jet chamber in the White and Poppe is of a considerable capacity, and in closing the throttle there is an absence of that concentration of air-flow which is generally desirable for slow running purposes.

There is, however, a certain amount of wire drawing of the air stream on the inlet side to the throttle which is silenced effectively by means of two corrugated strips of copper, as wire drawing in the ordinary way produces an objectionable noise when the engine is working.

Zenith.—Two-jet or multi-jet carburettors working on varying suctions are examples of the diversion of the air stream under no load or light load conditions of work-

ing. The Zenith (Fig. 69) is one of the most popular of this type of instrument, and here we have a subsidiary petrol duct fed from the float chamber at a constant rate of flow by means of a suitable checking device. This secondary supply rises up a small tube opened to the atmosphere at the top, and dipping into it is an internal

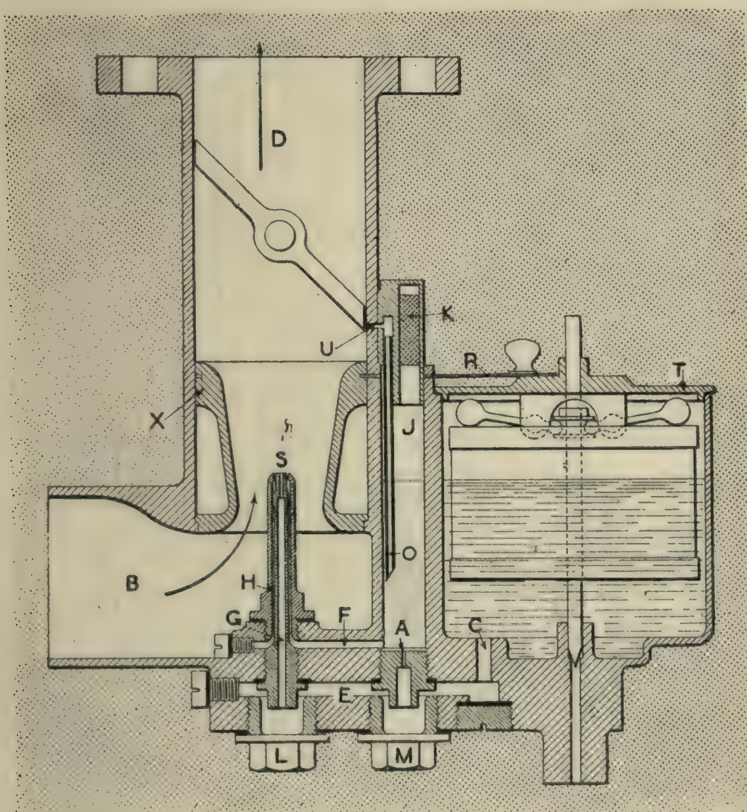

FIG. 69.—Zenith Two-Jet Carburettor.

pipe carried up to a point in the vicinity of the throttle valve. Although the suction due to slow running may be insufficient to cause the petrol to flow through the main jet, it will suffice for drawing enough liquid up to the subsidiary tube, the point of discharge of which is situated in a restricted part of the gas outlet from the carburettor.

In designing this carburettor the following essentials have been borne in mind: that carburation should be unaffected by the variation in the speed of the engine or of throttle

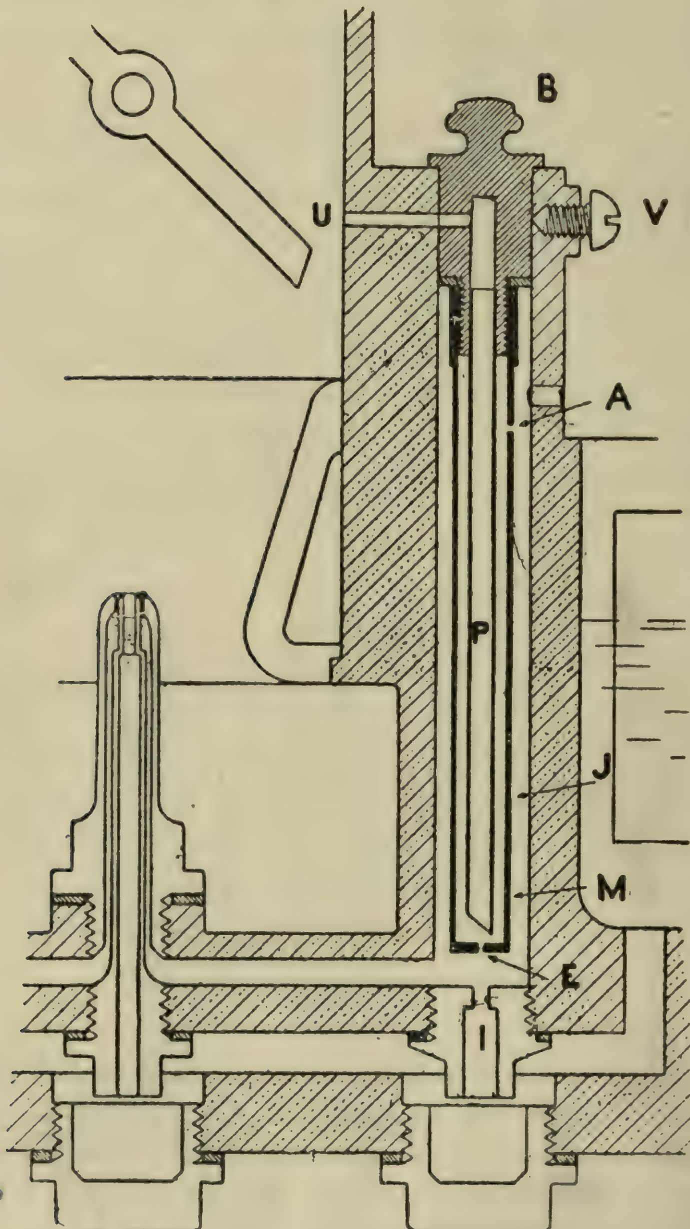

FIG. 70.—The "M. P." Jet Arrangement for Zenith.

opening, that the engine should pick up quickly and start easily from cold, and that the carburettor should be devoid of moving parts. With regard to speed variation and throttle opening, any good design of carburettor should be independent of these, but it is still a moot point as to whether a moving part, if simply constructed and not liable to suffer from wear, is a disadvantage or not.

Reverting to the curves of petrol flow previously referred to, it will be remembered that in apparatus of this kind, where the difference of pressure between that of the atmosphere and that in the vicinity of the jet varies throughout the working range, the flow of petrol does not vary in direct proportion. In the Zenith carburettor the compensating jet is introduced in order to give a flow of petrol in inverse ratio to that of the main jet. If the design is correct in any particular case, the result should be a straight line curve for the petrol flow. The duplex jets of the Zenith carburettor are arranged concentrically, and their levels coincide, the central jet communicating with the float chamber, while the external jet communicates with the small tube into which the starting tube also dips. The flow of fuel to the external jet is controlled by a choking plug, the size of which can be arrived at by trial and error. This carburettor is supplied with a Venturi tube, situated in the vicinity of the jet, and so there are three variables capable of adjustment, as follows :—

a. The main jet.
b. The choking plug controlling the external jet.
c. The Venturi tube.

The Zenith carburettor, like the White and Poppe, depends for its heat supply upon the necessary heat being added to the incoming air, as there is no jacket to the carburettor itself. The principle of this carburettor is based on Rummel's formula, given on p. 61.

Jets.—The new and modified means of adjusting the low load or starting jet, lately adopted by the Zenith

Carburettor Company, will be readily grasped by reason of its extreme simplicity.

The well above the compensator, in this new system, does not as usual hold the tube through which the petrol for slow running passes, but this tube is screwed inside another tube M, with a petrol inlet E of definite size drilled in the bottom of it, and an air hole A, also of definite size, at the side of the tube near the top.

The part B has two passages drilled at right angles to one another, with a milled knob which makes a push-fit in the well J. These passages coincide with the outlet U in the mixing chamber, which is situated just behind the edge of the butterfly throttle when closed. A pipe P, bevelled at the bottom, is fixed in the vertical hole in piece B, and dips down into the petrol in the intermediate tube M. This intermediate tube M is fed by the compensator I, and is placed in the well J.

The suction at the petrol inlet E, and the flow of air into the tube M, are both controlled by means of the hole A drilled in this tube.

The sizes of the holes A and E in the tube M are entirely independent of the size of choke tube, main jet, and compensator, and are the only things to be considered in adjusting this slow running device. Neither the length of the dip pipe P nor the tube M affects the adjustment, which is carried out after the ordinary tubing has been done.

APPENDIX I

TABLE LVI.—EQUIVALENTS.

1 calorie (major)	= 3.968 B.Th.U.
1 B.Th.U.	= 0.252 calorie.

ERRATUM

APPENDIX I. TABLE LVI.—EQUIVALENTS

For "1 calorie per kilog. = 3.967 B.Th.U." *read* "1 calorie = 3.967 B.Th.U."

[*To face page* 240.

1 gal.	= 4.546 cu. cms. = 0.1606 cub. ft.
1 cub. ft.	= 28.3 litres. = 6.28 gals.
1 inch of water gauge	= 25.4 mm. water gauge.
1 American gal.	= 0.832 imperial gal.
1 Imperial gal.	= 1.2012 American gal.
1 Imperial gal.	= 4.546 litres.
1 American gal.	= 3.784 litres.
1 litre	= 0.2622 American gal.

Carburettor Company, will be readily grasped by reason of its extreme simplicity.

The well above the compensator, in this new system, does not as usual hold the tube through which the petrol for slow running passes, but this tube is screwed inside another tube M, with a petrol inlet E of definite size drilled in the bottom of it, and an air hole A, also of definite size, at the side of the tube near the top.

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APPENDIX I

TABLE LVI.—EQUIVALENTS.

1 calorie (major) - -	= 3.968 B.Th.U.
1 B.Th.U. - - -	= 0.252 calorie.
1° C. - - - -	= $\frac{9}{5}$° F.
1° F. - - - -	= $\frac{5}{9}$° C.
1 kilog. - - - -	= 2.204 lbs.
1 lb. - - - -	= 0.453 kilog.
1 B.Th.U. per cub. ft. -	= 9 calories per cubic metre approx.
g - - - - -	= 32.2 ft. per sec. per sec. = 981 cm. per sec. per sec.
$\frac{1}{273}$ per ° C. - - -	= $\frac{1}{491}$ per ° Fahr.
1 kilog. per sq. cm. - -	= 14.2 lbs. per sq. in.
1 lb. per sq. in. - -	= 0.0703 kilog. per sq. cm.
1 metre kilog. - - -	= 7.231 ft. lbs.
1 ft. lb. - - - -	= 0.138 metre kilog.
1 metre - - - -	= 39.37 in. = 3.281 ft.
1 ft. - - - - -	= 0.3048 metre.
1 cub. metre - - -	= 35.31 cub. ft.
1 litre - - - -	= 0.22 imperial gal. = 0.03531 cub. ft.
1 calorie per kilog. - -	= 3.967 B.Th.U. per lb.
1 gal. - - - -	= 4.546 cu. cms. = 0.1606 cub. ft.
1 cub. ft. - - - -	= 28.3 litres. = 6.28 gals.
1 inch of water gauge -	= 25.4 mm. water gauge.
1 American gal. - - -	= 0.832 imperial gal.
1 Imperial gal. - - -	= 1.2012 American gal.
1 Imperial gal. - - -	= 4.546 litres.
1 American gal. - -	= 3.784 litres.
1 litre - - - -	= 0.2622 American gal.

TABLE LVII.—CONVERSION FROM DEGREES BAUMÉ TO SPECIFIC GRAVITY.

Degrees Baumé.	Specific Gravity.	Degrees Baumé.	Specific Gravity.	Degrees Baumé.	Specific Gravity.
10	1.000	34	0.853	56	0.753
12	0.986	36	0.843	58	0.744
14	0.972	38	0.833	60	0.737
16	0.959	40	0.823	62	0.729
18	0.946	42	0.814	64	0.721
20	0.933	44	0.804	66	0.714
22	0.921	46	0.795	68	0.707
24	0.909	48	0.786	70	0.700
26	0.897	50	0.777	75	0.683
28	0.886	52	0.769	80	0.666
30	0.875	54	0.761	85	0.651
32	0.844				

APPENDIX II

NOTES FROM A PAPER BY MR G. H. BAILLIE

THE minimum temperature at which it is possible for a fuel to exist as vapour under normal atmospheric pressure is obtained from the vapour-tension curve of the fuel, which is a curve giving the minimum temperature at which the vapour has a certain pressure. The pressure of the vapour in the mixture depends on the proportions of the mixture, and can be calculated from the equation :—

$$p = \frac{760}{1 + v\delta};$$

where p is the pressure of the vapour, V is the volume of air in cubic metres which is mixed with 1 kg. of fuel, and δ is the density of the vapour of the fuel at normal temperature and pressure. From this equation and from the vapour-tension curves can be found the minimum temperature at which different pure fuels can exist as vapour. It has been found that the best results are obtained in an engine when the mixture contains about 30 per cent. more air than the quantity theoretically sufficient to completely burn the fuel. The results for four mixtures are given in Table LIX.

TABLE LIX.—MINIMUM TEMPERATURE AT WHICH FUEL CAN EXIST AS VAPOUR.

Air.	20 Per Cent. Less.	Right Amount.	20 Per Cent. More.	40 Per Cent. More.
Hexane - -	−14.2	−17.7	−20.6	−24.2
Heptane - -	7.3	3.6	0.7	2.0
Octane - -	22.9	19.0	16.0	13.0
Decane - -	46.1	42.0	39.0	36.5
Benzene - -	−0.7	−4.3	−6.9	−8.3
Ethyl alcohol -	26.5	23.3	20.7	17.8

From the above table it appears that octane, decane, and alcohol cannot exist as vapour under ordinary atmospheric conditions except in very weak mixtures. The large difference between benzene and alcohol accounts for some of the difficulty in using the latter as compared with the former in an engine.

If these fuels were mixed with the air in the form of liquid at these temperatures they would not vaporise completely, for in evaporating they reduce the temperature, and the fall in temperature due to evaporation, calculated from the latent heats of the fuel and the specific heat of the air, is shown in Table LX.

TABLE LX.—DROP IN TEMPERATURE DUE TO EVAPORATION.

Air.	20 Per Cent. Less.	Right Amount.	20 Per Cent. More.	40 Per Cent. More.
Hexane - -	23.3	19.0	16.3	14.2
Heptane - -	22.4	17.9	15.0	12.8
Octane - -	21.5	17.2	14.3	12.3
Decane - -	18.5	14.8	12.4	10.6
Benzene - -	47.3	32.2	23.5	20.9
Ethyl alcohol -	95.5	76.3	63.7	54.6

Alcohol lowers the temperature in evaporating twice as much as benzene does, and benzene, according to Table LIX., can vaporise at about the same temperature as heptane.

If the figures in Tables LIX. and LX. be added together, the result gives the minimum temperature of the air necessary to evaporate the fuel completely. This is shown in Table LXI.

TABLE LXI.—MINIMUM TEMPERATURE OF AIR BEFORE EVAPORATION.

Air.	20 Per Cent. Less.	Right Amount.	20 Per Cent. More.	40 Per Cent. More.
Hexane - -	9.1	1.3	−4.3	−10.0
Heptane - -	29.7	21.5	15.7	10.8
Octane - -	44.4	36.2	30.3	25.3
Decane - -	64.6	56.8	51.4	47.1
Benzene - -	46.6	27.9	16.6	12.6
Ethyl alcohol -	122.0	99.6	84.4	72.4

None of the fuels above mentioned, hexane excepted, can be evaporated completely in a cold engine, whilst for complete evaporation alcohol requires the air to be at the boiling point of water. With 20 per cent. more air, heptane and hexane can be vaporised cold. It is a noteworthy fact that the temperature required for benzene falls very rapidly as the mixture becomes weaker.

An important factor in the question is the rate of evaporation. The time available is not nearly enough to evaporate the fuels at the minimum temperature, and the evaporation of liquid gets slower and slower as the space into which it evaporates becomes filled with vapour.

August's approximate law states that the time required for evaporation is proportional to $\log \frac{P}{P-p}$, where P is the maximum and p is the actual vapour pressure at the temperature in question.

The effect of the time required for evaporation can be estimated only by calculating from this expression the different temperatures which will cause the fuels to evaporate in the same time, and by assuming for one fuel, say hexane, that a certain increase of temperature above the minimum is required to evaporate it sufficiently fast, making the assumption that for hexane in a theoretically correct mixture the air should be at the normal temperature of 15° C., that is, that 13.7° must be added to the minimum temperature in order to evaporate the fuel quickly enough. On this basis, the calculations giving the additional temperatures to be added in the case of the other fuels, to produce evaporation in the same time, give values which, used in conjunction with the previous table, produce Table LXII.

TABLE LXII.—TEMPERATURES BEFORE EVAPORATION TO CAUSE EVAPORATION IN THE SAME TIME FOR EACH FUEL.

Air.	20 Per Cent. Less.	Right Amount.	20 Per Cent. More.	40 Per Cent. More.
Hexane - -	26.8	15.0	6.6	−0.8
Heptane - -	71.4	58.4	48.7	40.2
Octane - -	104.6	91.4	81.0	72.4
Decane - -	149.3	136.0	126.4	118.4
Benzene - -	81.0	57.3	42.3	38.4
Ethyl alcohol -	181.9	154.3	135.4	120.3

The proportion of these temperatures which represents the time element is certainly somewhat arbitrary, but the figures represent as closely as is possible on theoretical grounds the temperatures which would render the different fuels equally volatile under running conditions of a motor car.

Benzene has a higher boiling point than alcohol, and, as shown in Table LXI., it is far more volatile than alcohol under engine conditions, and for this reason it may be concluded that the calculations leading up to Table LXI. give a better idea of the volatility than do the boiling points, but it must be remembered that these calculations are applicable only to pure substances and not to our actual fuels, which are mixtures.

A mixture of two hydrocarbons in a certain proportion gives off vapour which also contains the two hydrocarbons in a certain definite but different proportion, there being more of the lighter constituents in the vapour than in the liquid, and the presence of the lighter constituents enables the heavier to evaporate more readily than they would alone. A petrol, then, evaporates as a whole, heavier constituents evaporating more slowly than the lighter, but more quickly than would be the case were they not mixed. It is, therefore, impossible to calculate the volatility of these complex mixtures, even if all the constituents are known, and it can only be found experimentally.

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